BRADLEY FIGHTING VEHICLE SYSTEM (U)

PHASE II LIVE FIRE TEST REPORT (U)

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Submitted by:

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(Test and Evaluation/Live Fire Testing)

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PREFACE

This report has been edited to prepare it for public release under the Freedom of Information Act. Classification of the original report was verified against the Bradley Fighting Vehicle Systems Security Classification Guide dated 1 May 1990. All classified information has been removed. Each paragraph that was removed has been replaced with ellipsis points (....). Tables that contained classified data were removed and only the unclassified titles were retained. The Table of Contents has been redone to conform with the new pagination that resulted from the removal of classified information. The List of Tables has been modified to indicate which tables were classified.

BRADLEY FIGHTING VEHICLE SYSTEM PHASE II LIVE FIRE TEST REPORT

TABLE OF CONTENTS

LIST OF TABLES

HS	High Survivability
IFV	Infantry Fighting Vehicle (M2)
ISU	Integrated Sight Unit
K-kill	Catastrophic Loss
KE	Kinetic Energy
LAW	Light Armored Weapon
LOF	Loss of Function
M-kill	Fractional Mobility Loss
NBC	Nuclear, Biological, Chemical
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
RPG-7G	A Soviet infantry antiarmor weapon (rocket propelled grenade)
SDAL	Standard Damage Assessment List
TMN-46	A Soviet blast/fragmentation antiarmor mine
TOW	Tube-launched, Optically-guided, Wire-tracked missile

GLOSSARY

AFSS	Automatic Fire Suppression System
APDS	Armor Piercing Discarding Sabot
ASTB	Advanced Survivability Test Bed
ATGM	Antitank Guided Missile
B	Basic Bradley Configuration
BAD	Behind Armor Debris
BAST	Board on Army Science and Technology
BFVS	Bradley Fighting Vehicle System
BH&T	Ballistic Hull and Turret
BMP-2	A Soviet light armored vehicle
CARDE	Canadian Armament Research and Development Establishment
CFV	Cavalry Fighting Vehicle (M3)
DDR&E	Director of Defense Research and Engineering
DOT&E	Director, Operational Test and Evaluation
DRAGON	Medium Infantry Antitank Weapon
DT	Developmental Testing
DTP	Detailed Test Plan
EC	Expected Casualties
F-kill	Fractional Firepower Loss
HE	High Explosive
HEAT	High Explosive Antitank
HEI-T	High Explosive Incendiary with Tracer
HQDA	Headquarters, Department of the Army

INTRODUCTION (U)

(U) This is a report on the Bradley Fighting Vehicle System (BFVS) Phase II Live Fire Test conducted from October 1986 to May 1987 at the Aberdeen Proving Ground, MD. It was prepared for the Office of the Secretary of Defense (OSD) as an independent report, based primarily on the observations of representatives of the Live Fire Test Office of OSD who attended each firing, supplemented by data supplied by the Army.

(U) The purpose of this report is:

- To evaluate the Bradley vulnerabilities and the effectiveness of various design concepts in reducing those vulnerabilities, based on the results of the Phase II Live Fire Test,
- To determine the implications of the Bradley Live Fire Test with respect to the conduct of future live fire tests, and
- To compare the conclusions of this report, regarding the Bradley vulnerabilities, to the conclusions of the Army Phase II Live Fire Test Report (Ref. 1).

(U) The following points, which provide a background for the results, are expanded in this section.

- The System tested was the Bradley Fighting Vehicle System.
- The test was a distinctive kind of vulnerability test, called a live fire test.
- The test was the second part of a three-phased effort, called the Bradley Survivability Enhancement Program.
- The primary objectives of the Phase II Live Fire Test were to determine, for specific threats:

  1. The relative vulnerabilities of a baseline Bradley and two enhanced configurations designed to reduce vulnerabilities.
  2. The effectiveness of each enhancement feature at reducing casualties and system vulnerability.
  3. The sources of crew casualties and the relative contributions of casualty producing mechanisms.

- The primary measures of vulnerability were:

1. Crew casualties (EC),
2. System loss of mobility (M-kill),
3. System loss of firepower (F-kill), and
4. System catastrophic loss (K-kill).

- The test assets included 16 Bradley vehicles for full-up live fire testing.
- The data available for analysis included the results of 86 shots.
- The Live Fire Test results must at least be combined with the results of separate operational tests to fully evaluate the payoffs of the concepts tested.

A. THE BRADLEY FIGHTING VEHICLE SYSTEM (U)

(U) The Bradley Fighting Vehicle System is produced in two configurations. The Infantry Fighting Vehicle (IFV) is denoted the M2, and the Cavalry Fighting Vehicle (CFV) is denoted the M3. The primary differences are that the M2 carries nine persons versus five for the M3, and that the M2 has an ammunition load approximately one-half that of the M3. Of the nine persons aboard the M2, three are crew and six are members of an infantry squad whose role is to fight dismounted as part of a combined arms team. The combined arms team includes tanks, helicopters, light armored vehicles and infantry.

(U) Though the Bradley has the capability to kill tanks, it is not as heavily armored as a tank. One therefore would not expect the Bradley to be exposed to the same distribution of threats as a tank. The Bradley may be exposed on occasion, however, to antitank threats. Operational tests, the data from which are not yet available, will help to determine a realistic threat distribution for the Bradley vehicles.

B. THE LIVE FIRE TEST (U)

(U) The test reported here was a distinctive kind of vulnerability test, called a live fire test, the purpose of which was to determine the effects of actual threat munitions hits on the Bradley vehicle. The distinctive features of the Bradley Live Fire Test were:

- **Fully combat-configured target system**, including full complements of fuel, ammunition, hydraulic fluid and stowage items.
- **Overmatching threats**, i.e., those considered likely to penetrate the vehicle's armor under certain conditions.
- **Realistic firing conditions** ("dynamic firings") of threat munitions.
- **Instrumentation to determine casualties.**

- **Both random and prescribed shots.** Shots were randomly selected with respect to shotline geometries only, not with respect to threat selection. The random shotlines were generated to conform to distributions considered roughly combat realistic, according to a methodology proposed by a committee of the Board on Science and Technology (BAST) under the auspices of the National Academy of Sciences (Ref. 2). The random shots do not, therefore, conform to a uniform distribution of shotlines. After the random shots were generated, additional shots were prescribed to address issues known to be important, such as the effectiveness of certain enhancement features, and for which the random firings were not expected to provide adequate information.
- **Offline tests** (subtests) to aid in the interpretation of the full-up tests by isolating damage effects in a controlled environment.
- **Provision for conceded shots.** In order to conserve targets, OSD and the Army agreed to the following ground rules for conceding a shot: that sufficient data exist to make the judgment of a catastrophic loss; that both the vehicle and all crew be scored as lost; and that the shot be included in the weighting of any overall assessment of vehicle vulnerability.

(U) The Bradley Live Fire Test differed from developmental ballistic testing (Ref. 3) in that the purposes of the developmental testing were restricted to verifying that protection requirements were satisfied, as opposed to determining the extent of damage produced by overmatching threats. The Live Fire Test differed from operational tests in that operational tests are typically not destructive. Table 1 summarizes the essential differences between live fire tests and operational tests.

(U) The Bradley Live Fire Test represents the most extensive live fire test to date in terms of cost, instrumentation and volume of data collected. Tests conducted in 1959 at the Canadian Armament Research and Development Establishment (CARDE) (Ref. 4) had previously been considered the most extensive live fire test.

(U) Live fire tests are expected to receive more attention as a result of the FY 1987 Department of Defense Authorization Act (Ref. 5). Realistic vulnerability/lethality testing, with emphasis on casualty reduction, is now required by law prior to full scale production of major conventional systems. The law requires the firing of munitions likely to be encountered in combat at a target fully equipped and ready for combat.

Table 1. (U) Live Fire Testing Versus Operational Testing

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LIVE FIRE TESTING	OPERATIONAL TESTING
• FULL-UP DESTRUCTIVE TESTING	• TYPICALLY NON-DESTRUCTIVE TESTING
• VEHICLE INSTRUMENTED TO GATHER BALLISTIC AND CREW CASUALTY DATA	• VEHICLE INSTRUMENTED SO AS NOT TO INTERFERE WITH TACTICAL REALISM
• DESIGN ORIENTED	• USER ORIENTED
• ONE-ON-ONE TESTS	• FORCE-ON-FORCE TESTS
• LETHALITY/VULNERABILITY	• SUSCEPTIBILITY

C. THE BRADLEY SURVIVABILITY ENHANCEMENT PROGRAM (U)

(U) The Bradley Phase II Live Fire Test was the second part of a three-phased effort called the Bradley Survivability Enhancement Program.

1. Phase I - Live Fire Test of Basic Bradley (U)

(U) Phase I testing, begun in October 1984, was a test of the vulnerabilities of the production version of the Bradley. Two purposes of the Phase I test were to provide baseline data to aid in the design of "quick fixes" to the production vehicles, and to guide the development of the enhanced vehicle designs tested in Phase II. The Phase I test also provided comparative data for the analysis of Phase II test results. The Phase I report (Refs. 6 and 7) contained the results of 68 firings against Ballistic Hull and Turret (BH&T) and M3 Cavalry Fighting Vehicle (CFV) targets. Twenty-two firings were against the BH&T, 36 were against production M3 vehicles containing inert ammunition, and the final 10 were against combat configured M3's containing live ammunition.

2. Phase II - Live Fire Test of Enhanced Configurations (U)

(U) The Phase II Live Fire Test was against Bradley Fighting Vehicle Systems (both the M2 and M3 configurations) that incorporated specific design enhancements intended to reduce the vulnerabilities of the vehicle and/or crew, while considering fightability, cost, weight and production schedule constraints. Two design concepts were tested, designated the High Survivability (HS) and Advanced Survivability Test Bed (ASTB) concepts. In contrast, the production vehicle tested in Phase I (and again in Phase II) is referred to as the Basic (B) vehicle.

(U) Table 2 summarizes the vulnerability reduction features of the HS and ASTB concepts. The HS was the initial proposal of the Army to reduce the Bradley's vulnerability in response to the results of Phase I testing. The ASTB was developed to allow alternative survivability enhancements to be tested, resulting in a test bed vehicle roughly corresponding to a design concept termed the "minimum casualty vehicle" (Ref. 5).

Table 2. (U) Vulnerability Reduction Features of HS and ASTB Bradley Vehicles

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(U) Simply stated, the HS vehicle seeks to minimize perforation into the vehicle, while the ASTB seeks to protect the crew by isolating them from the effects of explosive events involving fuel and ammunition. The distinctive design feature of the High Survivability vehicle is the use of reactive armor to minimize perforation of the vehicle. The distinctive design feature of the ASTB vehicle is the compartmentation of fuel and ammunition so as to isolate the crew from explosive events involving fuel and ammunition. Together, the two configurations enabled a larger number of survivability enhancement features to be tested than would have been possible had only one configuration been tested.

3. Phase III - Model Improvements and Payoff Analyses (U)

(U) Phase III of the Bradley survivability enhancement program, not yet completed, consists of an analysis of the adequacy of the computer model predictions, the implementation of improvements to the vulnerability model based on the Live Fire Test, and an evaluation of the payoffs of concepts tested in Phase II, using the results of the operational and live fire tests in conjunction with the improved vulnerability model.

D. TEST OBJECTIVES (U)

(U) The primary objectives of the Phase II Live Fire Test were to determine, for specific threats:

- The relative vulnerabilities of the production Bradley and the HS and ASTB Bradley configurations,
- The effectiveness of each enhancement feature in reducing casualties and system vulnerability, and

- The sources of crew casualties and the relative contributions of casualty producing mechanisms.

E. MEASURES OF VULNERABILITY (U)

(U) The primary measures of vulnerability were:

- Crew casualties (EC),
- System loss of mobility (M-kill),
- System loss of firepower (F-kill), and
- System catastrophic loss (K-kill).

(U) The emphasis of the test was on crew casualties. The vehicles were instrumented to determine the effects on crew of penetrators, spall, toxic fumes, overpressure, shock/acceleration, fire and flash.

F. TEST ASSETS (U)

(U) The test assets included 16 Bradley vehicles for full-up live fire testing. Table 3 lists the numbers of each type of vehicle. Because the ASTB was a test bed, only three of these vehicles were constructed and available for the live fire test.

Table 3. (U) Live Fire Test Vehicle Assets

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Bradley Type	Vehicle Configuration		
	Basic	HS	ASTB
M2	4	2	1
M3	3	4	2

G. ANALYSIS (U)

(U) The data available for analysis included the results of 86 shots. In Phase II there were 73 test firings, 4 conceded shots, and 1 repeated Phase II shot due to warhead malfunction. In addition, 7 shots from Phase I and 1 from developmental testing were matched with Phase II shots.

(U) The Live Fire Test was a vulnerability test, i.e., a test of the ability of a Bradley to withstand a hit. An analysis of total system survivability and an evaluation of the payoffs of the tested enhancement concepts is dependent on the merging of these test results with the results from operational testing and other considerations.

(U) Nevertheless, the Summary section which follows contains preliminary evaluations of the design concepts based on available data. The Summary is intended to provide a "crosswalk" to be used with the operational test results when they become available. Because vulnerability models will be used by the Army for extrapolation of test results, this report also addresses the predictive accuracy of the models based on the Phase II test.

SUMMARY (U)

(U) This summary consists of three parts. The first part contains results and conclusions related to the primary objectives of the Bradley Live Fire Test. The second part lists implications of the Bradley Live Fire Test with respect to the conduct of future live fire tests. The third part consists of a comparison of the conclusions of this report with those of the Army report.

A. PRIMARY RESULTS AND CONCLUSIONS REGARDING THE BRADLEY VULNERABILITIES (U)

1. Relative Vehicle Vulnerabilities (U)

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(U) Table 4 summarizes the relative vulnerabilities of the three configurations (Basic, HS and ASTB) for each threat munition. The threat weapons, while not comprehensive, were considered representative of a spectrum of current overmatching threats that the Bradley might be expected to encounter in combat. Overmatching threats are those considered likely to penetrate the vehicle's armor under certain conditions. The RPG-7G was considered representative of the class of Soviet small caliber high explosive anti-tank (HEAT) weapons carried by infantry, while the TOW and TOW 2 were surrogates for Soviet heavy anti-tank guided missiles (ATGMs). The 120mm HEAT and KE projectiles were considered representative of the Soviet large caliber tank rounds, and the 30mm APDS projectile was considered representative of those that could be fired from the Soviet BMP-2. The TMN-46 is a Soviet anti-tank blast/fragmentation mine.

Table 4. (U) Relative Vulnerabilities of the Bradley Test Configurations (Basic, High Survivability and Advanced Survivability Test Bed)

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a. Light Armored Vehicle Automatic Cannon Threat (30mm KE) (U)

(~~S~~ U) ....

b. Infantry Shaped Charge Threat (RPG-7G) (U)

(~~S~~ U) ....

(~~S~~ U) ....

c. Antiarmor Blast/Fragmentation Mine Threat (TMN-46) (U)

(~~S~~ U) ....

d. Tank Gun Threats (120mm HEAT and KE), and Heavy ATGM Threats (TOW and TOW 2) (U)

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2. Effectiveness of Enhancement Features (U)

(U) A second objective of the test was to determine the effectiveness of each of the enhancement features (see Table 2) in reducing casualties and system vulnerability. Because the live fire tests were against complete systems, it was not always possible to isolate the contributions of each vulnerability reduction feature. The offline test results were useful in interpreting the live fire test results and providing additional information in such cases.

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3. Crew Casualties (U)

a. Expected Crew Casualties (U)

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(~~S~~ U) ....

b. Comparison of M2 and M3 Casualties (U)

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c. Casualty Producing Mechanisms (U)

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B. IMPLICATIONS OF THE BRADLEY LIVE FIRE TEST WITH RESPECT TO THE CONDUCT OF FUTURE LIVE FIRE TESTS (U)

1. Assessment of Casualties and System Damage (U)

(U) The instrumentation developed for the Bradley live fire test represents a significant improvement over past vulnerability tests. In particular, internal and external video cameras enabled assessors to better determine the probable sequence of events and crew ability to fight fires, and enabled real time fire suppression decisions which helped prevent loss of target vehicles. In addition, instrumentation for toxic fumes permitted measurements which contributed significantly to casualty assessments. However, there is a need to improve and validate the methodologies for evaluation of overpressure and toxic fume data.

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(U) More evidence is needed on likely crew response to slow developing fires and to the trauma of being hit. Information regarding crew response is important both for more realistic casualty and vehicle damage assessments, and for the improvement of crew training.

(U) The Standard Damage Assessment List (SDAL) used by the assessors in converting physical damage to system loss of function (mobility or firepower) is highly

subjective by nature and requires documentation for future live fire tests. Documentation on the development of the Bradley SDAL is apparently non-existent. Also, it would be desirable to have independent development of the SDAL by different teams to enable an estimate of the variability of its contents.

2. Shot Selection (U)

(U) The random (BAST methodology) and prescribed ("engineering assessment") shots each played a unique and necessary role in live fire testing. The random shots were important: (1) in those instances where a combat realistic shot selection was called for by the evaluation plan; (2) to eliminate the perception of institutional bias; (3) to permit the possibility of surprises; and (4) to make sure that both the vehicle and models received a comprehensive test. The perception of institutional bias might be eliminated by other means, but the other reasons for random testing remain valid. The proportion of random shots, however, is likely to vary depending on the test objectives and evaluation plan. (For Phase II, roughly two-thirds of the firings were randomly generated.) The prescribed shots can be more efficient in addressing issues known to be important and for which the random firings were not expected to provide adequate information. In general the off-line tests, by isolating damage effects in a controlled environment, can be useful in interpreting full-up results that otherwise may have been inconclusive.

3. The Vulnerability Models (U)

(U) The vulnerability models, particularly those that incorporate stochastic features, can be valuable for selecting shots that conform to test objectives, for sequencing of those shots (in general it is most efficient to test shots with least expected damage first), and for estimation of required test resources (catastrophic losses, spare parts). Furthermore, comprehensive vulnerability analyses require both an upgraded computer model and evidence directly obtained from live fire tests. Therefore, it is important that close coordination exist between the testing and modeling communities and that, as much as possible, data be collected from live fire tests that can be directly related to the required inputs of the vulnerability models. However, live fire testing does not and should not have as its primary goal the building of computer models, nor should test realism be overridden by the desire to fill data voids.

(U) The computer model predictions, in the form provided to OSD, were of very limited utility in determining the model's predictive capability. Part of this problem is

inherent in the vulnerability model used for the Bradley test, which predicts average damage over a large set of possibilities and does not account for the variety of possible damage states that could result from stochastic variability given a shotline. Some test results indicate that test shots intended to be exact replications may vary greatly in damage produced. The other problem with using the computer predictions provided was that no predictions were made available for the actual impact points using the pre-test version of the model. An analysis of the model's predictive capability could be improved in future live fire tests by exercising a stochastic vulnerability model and then providing predictions using the actual impact point from both the pre-test model and the model incorporating changes based on test results.

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Some of these model changes have already been made based on the live fire tests.

4. Target Realism (U)

(U) For range safety reasons, all but one of the live fire tests were conducted against targets whose stowed ammunition contained inert fuzes, though otherwise the ammunition was live. There are indications that for the Bradley vehicles tested there was no measureable difference in effects whether the 25mm HEI ammunition was live fuzed or inert fuzed. The issue of the comparative effects of firings against targets with live fuzed versus inert fuzed stowed ammunition will have to be addressed in all live fire armor tests. If at all possible, this issue should be resolved through off-line tests interpreted by an analysis of the fuze designs of the stowed munitions.

C. COMPARISON OF THE ARMY REPORT AND THIS REPORT ON THE BRADLEY FIGHTING VEHICLE SYSTEM (BFVS) PHASE II LIVE FIRE TESTS (U)

(U) A comparative review was made of the Bradley Phase II results as presented in the Army report and in this report. The draft Army report on the Phase II Live Fire Test (Ref. 1) was provided subsequent to the preparation of Sections I and II of this report. Sections I and II (and the Summary thereof) were thus independently developed and not influenced by the Army's reported findings. It was assumed that the main points of each report were developed in their respective executive summaries. These were the primary sources for comparison of the two reports.

(U) This review did not address the contents of the Phase II test plans; they were approved by both Department of the Army and by OSD. However, lessons learned in the Bradley tests may affect the planning for subsequent tests of armored vehicle vulnerability and are discussed in Section B of the Summary. Details of similarities and differences in the two reports are presented in Section III of the Discussion. Addressed there are matters related to execution of the test plan, presentation and analysis of the test data, results and conclusions. There follows below a summary of differences found in the comparative review.

1. Future Threats (U)

(U) The Army report characterizes the TOW/TOW 2 as representative of current and future Soviet anti-tank guided missiles (p. iv), whereas this report describes the threat weapons to be representative of current overmatching threats (p. 9). (See related comment in Section III.F.)

2. Stowage of Live-Fuzed vs. Inert-Fuzed Ammunition (U)

(~~C~~ U) ....

(U) This report states (p. 36) that:

> (U) Although the full-up test and off-line tests alone were considered inconclusive, additional tests...showed virtually no difference in the likelihood of sympathetic detonation to adjoining rounds whether the 25mm HEI-T test rounds were live fuzed or inert fuzed. Further, the design of the fuze was considered to preclude the possibility of a difference in effects. Therefore, additional tests were not considered necessary <u>in this case</u>.

(U) The situation in any future test will depend on the actual munitions involved, including their fuze designs and explosive sensitivities. For this reason this report states that for future tests, the issue of comparative effects for live and inert-fuzed stowed ammunition should be examined through off-line tests.

(U) In summary, the conclusions reached in this and the Army report do not differ in any critical aspect; differences are due principally to different areas chosen for emphasis and to different modes of presentation.

3. Relative Vehicle Vulnerabilities to the 30mm KE threat (U)

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4. Overall Relative Vehicle Vulnerability (U)

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(U) This report devotes considerable attention to drawbacks as well as advantages of various survivability enhancement features, and the need for trade-off analyses which takes into account the results of operational tests (Section D, p.38).

5. Implications for Future Live Fire Tests (U)

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These issues were not directly addressed in the Army report.

DISCUSSION (U)

(U) The following section provides supporting documentation for the results and conclusions presented in the Summary. It includes:

- **Test Design and Conduct.** The Summary section identifed three test objectives as primary. However, it was clear from the shot selection rationale of the Detailed Test Plans (Refs. 8 and 9) that other objectives motivated the shot selection as well. Seven of these specific objectives are identified and discussed in this section, along with the additional parameters of pre-shot prediction accuracy and the role of subjective judgments in the assessment process.
- **Test Results and Analyses.** Results reported include not only the live fire test shots against full-up vehicles, but also results of offline subtests used to aid in the interpretation of the full-up tests by isolating damage effects in a controlled environment. Analyses include an evaluation of the predictive capabilities of the vulnerability models, the Bradley vulnerabilities to subsequent hits, and the sensitivity of results to assessor judgment, assumptions and definitions.

A. TEST OBJECTIVES (U)

(U) For the purposes of this report, it was helpful to distinguish the three primary objectives of the Bradley Phase II Live Fire Tests. These were determined from the stated purposes of the Bradley Survivability Enhancement Program, Phase II and from the priority given to casualty reduction, as evidenced by the test instrumentation and Congressional legislation (Ref. 5). The **primary objectives** appear three-fold. Determine, for specific threats:

1. The relative vulnerabilities of a baseline Bradley and two configurations designed to reduce vulnerabilities.

2. The effectiveness of each enhancement feature at reducing casualties and system vulnerability.

3. The sources of crew casualties, and the relative contributions of casualty producing mechanisms.

(U) The primary objectives formed the organizational structure for the report Summary. The Discussion requires a fuller elaboration in some areas, and is therefore organized around the specific objectives inferred from the shot selection rationale of the Detailed Test Plans (Refs. 9 and 10). The shot selection rationale gave no sense of overall priorities, which is why the specific test objectives were not used in the report Summary. (On the other hand, the explicit objectives in the Detailed Test Plans were too generally stated and thus were unsatisfactory in this respect.) The inferred ("specific") objectives were as follows.

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(U) The Live Fire Test was also expected to produce payoffs other than vulnerability assessment. These included information regarding battle damage assessment and repair, and spare parts stockage levels. No specific objectives were related to these potential payoffs, and the topics are not addressed in this report.

B. TEST PLAN (U)

(U) To fulfill the test objective, a total of 77 shots were selected using three methods: by random generation from a shot distribution similar to that expected in combat (51 shots), by matching a shot from Phase I to provide a direct comparison (13 shots), and by prescription to address specific issues not addressed by the other shots (13 shots).

(U) The 51 random shots were selected using a methodology proposed by the BAST committee (Ref. 2) specifically to address the crew casualty issues and for use in a pairwise comparison of effects between the Basic and HS vehicles. The random shots were considered necessary to both eliminate the perception of institutional bias and to ensure that both the vehicle and the models received a comprehensive test by permitting surprises (results contrary to expections), in addition to shots where expectations were uncertain (known data voids). Also, for certain of the analyses it was helpful to know the population from which the shots were drawn, in this case a distribution considered representative of combat. It should be noted that in order to address the issue of crew casualties, all random shotlines were required to pass through the crew compartment.

(U) The 13 prescribed shots (denoted "engineering assessment" shots by the Army) were selected after the random shots to address areas of potential vulnerability not captured by the random shot selection. The 13 Phase I repeat shots were selected to

enable the use of Phase I results in comparing the Basic vehicle with the two enhanced vehicles.

(~~C~~ U) ....

(U) Physical damage was converted to four measures of damage: expected casualties (EC), mobility loss (M-kill), firepower loss (F-kill) and catastrophic loss (K-kill). In some cases, assessors assigned fractional casualty values to some crew members. Fractional casualties represent the expected loss of combat capability when random elements and variability of human response to injury are considered. The measure "expected casualties" therefore represents total fractional casualties. Values of M-kill and F-kill represent fractional losses of combat utility as determined from the Standard Damage Assessment List (SDAL). The SDAL is a list of "critical" components together with a percentage loss of utility associated with each damaged component. (For this purpose certain crew members are considered as system components just as the engine would be.) K-kill is a categoric measure (yes or no). The criterion for K-kill was 100% M-kill, 100% F-kill, and an assessment that it was not feasible to repair the vehicle. The criterion for K-kill necessitated the scoring of 100% crew casualties, unless it was determined that crew members could have escaped violent reactions of stored combustibles.

(U) The Detailed Test Plans (Refs. 9 and 10) for the Phase II Live Fire Test were approved by both the Department of the Army and OSD. The firing matrix, summarized in Table 5, consisted of 77 planned full-up shots of which 73 were actually fired. The four which were not fired were conceded by the Army because they would most likely have resulted in catastrophic losses (i.e., complete loss of vehicle and crew). The ground rules established by OSD as a condition for conceding a shot as catastrophic required that sufficient data exist to make the judgment of a catastrophic loss, that both the vehicle and all crew be scored as lost and that the shot be included in the weighting of any overall assessment of vehicle vulnerability.

(U) All targets in Phase II were loaded with live ammunition whose fuzes, with one exception, were inerted for range safety reasons. Otherwise, all full-up firings were against combat configured vehicles with a full complement of fuel, ammunition, hydraulic fluid and stowage items. The engines were running at the time of the firings and fuel was heated to operational temperatures.

Table 5. (U) Distribution of Bradley Phase II Test Firings

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TYPE OF WEAPON	TYPE OF BRADLEY VEHICLE						TOTAL
	M2(B)	M2(HS)	M2(ASTB)	M3(B)	M3(HS)	M3(ASTB)	
30 mm KE			1	4	6	7	18
RPG-7G	3	3	5	8[a]	12[a]	11	42
120 mm KE					1		1
120 mm HEAT					3	1	4
TOW	1				1		2
TOW 2		1[b]			2[b]	1	4
TMN-46 MINE		1	1				2
TOTAL	4	5	7	12	25	20	73

[a]Does not include a firing repeated due to warhead malfunction or test problems
[b]Does not include two shots conceded as catastrophic losses of vehicle and all personnel.

(U) Six subtests were included in the Phase II test plan: 25mm ammunition compartmentation, 25mm ammunition reaction, Halon interactions, behind armor debris (BAD), ready box vulnerability, and live versus inert fuzed 25mm HE ammunition. The objective of these subtests was to aid in the interpretation of the full-up tests by isolating damage effects in a controlled environment.

(U) In addition to the Phase II test shots, the results from seven shots in Phase I testing and one shot in developmental testing (DT-II) were used, as planned, to supplement the test results. The Phase I shots were all against an M3(B) vehicle loaded with live ammunition and inert fuzes and consisted of four RPG-7 shots, two 120mm HEAT shots, and one TOW shot. The DT-II shot was a TMN-46 mine shot against an "IFV/CFV" (Ref. 3). Where appropriate and so identified, the results from four other live ammunition/inert fuze shots (2 RPG-7 and 2 TOW) and 36 inert ammunition/inert fuze shots (13 RPG-7, 8 TOW, 6 Rockeye II, 5 30mm KE and 4 M-70 mine) documented in the Phase I test report (Refs. 6 and 7) were also used in the analyses.

C. RESULTS (U)

(U) The reporting of results in this section is organized around the specific test objectives identified in Section A. It differs structurally from the Summary in that the Summary addressed only those results related to the primary test objectives. This section also reports the results of analyses of the Bradley vulnerabilities to subsequent hits, the sensitivity of results to assessor judgment, and an evaluation of the performance of the computer models used for pre-shot predictions.

(U) Table 6 summarizes the results of the test firings by threat against the various Bradley configurations. The BAST shots are listed separately since they were randomly drawn from a distribution of shotlines to approximate what might be expected in combat.

Table 6. (U) Summary of Results Based on Full-up Live Fire Shots Conducted in Phases I, IIA and IIB and a Mine Shot From DT-II

(~~SECRET~~ UNCLASSIFIED)

(U) It is noted that the overall level of casualties and damage is roughly the same over all shots as for the BAST (random) shots. This indicates that the prescribed shots, while of special interest because of the information to be obtained, do not appear in this case to bias the overall impression of the Bradley vulnerabilities.

1. Relative Vulnerabilities of the HS, ASTB and Basic Bradley Vehicles (U)

a. RPG-7G Threat (U)

(~~S~~ U) ....

(~~S~~ U) ....

(~~S~~ U) ....

b. 30mm KE Threat (U)

(~~C~~ U) ....

c. TOW, TOW 2 and 120mm Threats (U)

(~~S~~ U) ....

d. Vulnerabilities to Subsequent Hits (U)

(~~S~~ U) ....

e. Crew Casualties (U)

(~~S~~ U) ....

(~~S~~ U) ....

(~~C~~ U) ....

(~~S~~ U) ....

(~~C~~ U) ....

(~~C~~ U) ....

2. Relative Casualty Levels of the M2 and M3 Bradley Vehicles (U)

(~~S~~ U) ....

3. Effectiveness of High Survivability Reactive Armor (U)

(~~S~~ U) ....

(~~S~~ U) ....

(~~C~~ U) ....

(~~C~~ U) ....

(~~S~~ U) ....

(~~S~~ U) ....

(~~C~~ U) ....

4. Effectiveness of ASTB Survivability Enhancements (U)

a. Ammunition and Fuel Compartmentation (U)

(~~S~~ U) ....

(~~C~~ U) ....

(~~S~~ U) ....

b. Enhancements to Both the HS and ASTB Vehicles (U)

(~~S~~ U) ....

(~~C~~ U) ....

(~~S~~ U) ....

5. Effect of TMN-46 Mine (U)

(~~S~~ U) ....

6. Effect of a 30mm KE, 3-Round Burst Into Internal Fuel Cell (U)

(~~C~~ U) ....

7. Relative Effects of Live-Fuzed vs. Inert-Fuzed Stowed Ammunition (U)

(U) The issue of testing targets stowed with live ammunition with live fuzes is important and goes beyond questions of test realism, cost and scheduling. Current Army explosive ordnance safety procedures restrict any test personnel from entering such a target for post-shot vulnerability assessments if live fuzes are used. Although the hazards to test personnel caused by the live fuzing of 25mm HEI-T ammunition were considered minimal both in terms of likelihood and level of severity, any possibility of injury to test personnel is considered unacceptable. (The explosive material in a 25mm HEI-T fuze is about the size of a watch battery, and contributes less than one percent of the explosive content. Further, the fuze is designed so that when unarmed, as it is when combat stowed, the fuze will not initiate the rest of the round even if the fuze tip is damaged or burns. If the 25mm round is APDS, as are roughly one-fourth of the 25mm rounds carried on the Bradley, there is no warhead or fuze.)

(U) The safety procedures are considered appropriate. However, the question arises as to the relative tradeoff between a limited damage assessment when the live stowed ammunition contains live fuzes, versus a full damage assessment when the live stowed ammunition contains inert fuzes. This question cannot be adequately addressed unless one determines both the magnitude of and conditions for any differences in effects when ammunition is stowed either way.

(~~S~~ U) ....

(U) The results of off-line tests addressing this issue were similarly inconclusive, because of both the limited number of firings devoted to this issue as well as firings that

did not impact their intended locations due to dispersion induced by dynamic firing of the RPG-7G munitions.

(U) Although the full-up test and off-line tests alone were considered inconclusive, additional tests (Ref. 11) showed virtually no difference in the likelihood of sympathetic detonation to adjoining rounds whether the 25mm HEI-T test rounds were live fuzed or inert fuzed. Further, the design of the fuze was considered to preclude the possibility of a difference in effects. Therefore, additional tests were not considered necessary in this case.

8. Accuracy of Pre-Shot Predictions (U)

(~~S~~ U) ....

(U) The vulnerability model used for pre-shot predictions did not have the capability to account for the variety of possible damage states over repeated shots into the same impact point. Rather, the model employed by the Army for its "predictions" produced one overall estimate of the average of expected results. This average result may never occur for any single shot. Therefore, a detailed analysis of the predictive capability of the model was not considered appropriate on a shot-by-shot basis. Deviations from the predicted results were substantial for some shots, but the general trend was for moderate to good association between predictions and test results.

(U) Since the tests did not result in measures of the type constituting the basic inputs to the vulnerability model, any analysis of the causes of errors in predictive capability of the model must necessarily be based on indirect evidence.

(~~C~~ U) ....

(U) As a result of the tests, several of the above phenomena are currently being addressed.

9. Sensitivity Analyses (U)

(~~C~~ U) ....

D. EVALUATION OF THE EFFECTIVENESS OF ENHANCEMENT FEATURES (U)

(U) A primary objective of the test was to determine the effectiveness of each of the enhancement features (see Table 2) at reducing casualties and system vulnerability.

The test results are reported in Section C. However, an evaluation of these results must take into account any drawbacks associated with these features.

(~~S~~ U) ....

Table 7. (U) Weight Comparison Between the Bradley Test Vehicles

(~~SECRET~~ UNCLASSIFIED)

(U) For some enhancement features, the potential drawbacks are minimal. In such cases, little evidence of the effectiveness of that feature is required to support an evaluation that the feature is desirable.

(~~C~~ U) ....

(U) Table 8 summarizes the effectiveness of each enhancement feature tested. It contains, for each enhancement feature, the vehicle configuration on which that feature was tested, the desired effect of making the change, potential drawbacks, evidence of the effectiveness of the feature, and a summary evaluation. Reactive armor, the principal feature of the HS vehicle, is presented first, followed by ammunition compartmentation, a principal feature of the ASTB vehicle.

Table 8. (U) Evaluation of Vulnerability Reduction Features

(~~SECRET~~ UNCLASSIFIED)

(~~S~~ U) ....

(~~S~~ U) ....

(~~S~~ U) ....

Table 9. (U) Information Needed From Operational Test to Complete An Evaluation of Bradley Enhancements

(~~SECRET~~ UNCLASSIFIED)

I. TEST DESIGN AND CONDUCT (U)

A. TEST OBJECTIVES (U)

(U) For the purposes of this report, it was helpful to distinguish the three primary objectives of the Bradley Phase II Live Fire Tests. These were determined from the stated purposes of the Bradley Survivability Enhancement Program, Phase II and from the priority given to casualty reduction, as evidenced by the test instrumentation and Congressional legislation (Ref. 5). The primary objectives appear three-fold. Determine, for specific threats:

1. The relative vulnerabilities of a baseline Bradley and two enhanced configurations designed to reduce vulnerabilities.

2. The effectiveness of each enhancement feature at reducing casualties and system vulnerability.

3. The sources of crew casualties, and the relative contributions of casualty producing mechanisms.

(U) In addition, specific objectives were inferred from the shot selection rationale of the Detailed Test Plans (Refs. 9 and 10). These gave no sense of overall priorities, whereas the explicit objectives in the Detailed Test Plans were too generally stated. The Detailed Test Plans were unsatisfactory in this respect. The inferred objectives were as follows.

(S U) ....

B. TEST PLAN (U)

(U) To fulfill the test objectives, a total of 77 live fire shots were selected using three methods: by random generation from a shot distribution similar to that expected in combat (51 shots), by matching a shot from Phase I to provide a direct comparison (13 shots), and by prescription to address specific issues not addressed by the other shots (13 shots).

(U) The 51 random shots were selected using a methodology proposed by a committee from the Board on Army Science and Technology (BAST) (Ref. 2) specifically to address the crew casualty issues and for use in a pairwise comparison of

effects between the Basic and HS vehicles. The random shots were considered necessary to both eliminate the perception of institutional bias and to ensure that both the vehicle and the models received a comprehensive test by permitting surprises (results contrary to expections), in addition to shots where expectations were uncertain (known data voids). Furthermore, for certain of the analyses it was helpful to know the population from which the shots were drawn, in this case a distribution considered representative of combat. It should be noted that in order to address the issue of crew casualties, all random shotlines were required to pass through the crew compartment.

(U) The 13 prescribed shots (denoted "engineering assessment" shots by the Army) were selected after the random shots to address areas of potential vulnerability not captured by the random shot selection. The 13 Phase I repeat shots enabled the use of Phase I results in comparing the Basic vehicle with the two enhanced vehicles.

(~~C~~ U) ....

Table 10. (U) Distribution of Bradley Phase II Test Firings

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TYPE OF WEAPON	TYPE OF BRADLEY VEHICLE						TOTAL
	M2(B)	M2(HS)	M2(ASTB)	M3(B)	M3(HS)	M3(ASTB)	
30 mm KE			1	4	6	7	18
RPG-7G	3	3	5	8[a]	12[a]	11	42
120 mm KE					1		1
120 mm HEAT					3	1	4
TOW	1				1		2
TOW 2		1[b]			2[b]	1	4
TMN-46 MINE		1	1				2
TOTAL	4	5	7	12	25	20	73

[a]Does not include a firing repeated due to warhead malfunction or test problems
[b]Does not include two shots conceded as catastrophic losses of vehicle and all personnel.

(U) Physical damage was converted to four measures of damage: expected casualties (EC), mobility loss (M-kill), firepower loss (F-kill) and catastrophic loss (K-kill). In some cases, assessors assigned fractional casualty values to some crew members.

Fractional casualties represent the expected loss of combat capability when random elements and variability of human response to injury are considered. The measure "expected casualties" therefore represents total fractional casualties. Values of M-kill and F-kill represent fractional losses of combat utility as determined from the Standard Damage Assessment List (SDAL). The SDAL is a list of "critical" components together with a percentage loss of utility associated with each damaged component. (For this purpose certain crew members are considered as system components just as the engine would be.) K-kill is a categoric measure (yes or no). The criterion for K-kill was 100% M-kill, 100% F-kill, and an assessment that it was not economically feasible to repair the vehicle. The criterion for K-kill necessitated the scoring of 100% crew casualties, unless it was determined that crew members could have escaped any violent reactions of stowed combustibles.

(U) The Detailed Test Plans (Refs. 9 and 10) for the Phase II Live Fire Test were approved by both the Department of the Army and OSD. The firing matrix, summarized in Table 10, consisted of 77 planned full-up shots of which 73 were actually fired. The four which were not fired were conceded by the Army because they would most likely have resulted in catastrophic losses (i.e., complete loss of vehicle and crew). The ground rules established by OSD as a condition for conceding a shot as catastrophic required that sufficient data exist to make the judgment of a catastrophic loss, that both the vehicle and all crew be scored as lost and that the shot be included in the weighting of any overall assessment of vehicle vulnerability.

(U) All targets in Phase II were loaded with live ammunition whose fuzes, with the exception of one shot, were inerted for range safety reasons. Otherwise, all full-up firings were against combat configured vehicles with a full complement of fuel, ammunition, hydraulic fluid and stowage items. The engines were running at the time of the firings and fuel was heated to operational temperatures.

(U) Six subtests were included in the Phase II test plan: 25mm ammunition compartmentation, 25mm ammunition reaction, Halon interactions, behind armor debris (BAD), ready box vulnerability, and live versus inert fuzed 25mm HE ammunition. The objective of these subtests was to aid in the interpretation of the full-up tests by isolating damage effects in a controlled environment.

(U) In addition to the Phase II test shots, the results from seven shots in Phase I testing and one shot in developmental testing (DT-II) were used, as planned, to supplement the test results. The Phase I shots were all against an M3(B) vehicle loaded

with live ammunition and inert fuzes and consisted of four RPG-7 shots, two 120mm HEAT shots, and one TOW shot. The DT-II shot was a TMN-46 mine shot against an "IFV/CFV" (Ref. 2). Where appropriate and so identified, the results from four other live ammunition/inert fuze shots (2 RPG-7 and 2 TOW) and 36 inert ammunition/inert fuze shots (13 RPG-7G, 8 TOW, 6 Rockeye II, 5 30mm KE and 4 M-70 mine) documented in the Phase I test report (Refs. 6 and 7) were also used in the analyses.

(U) The following sections provide more detail concerning the shot selection rationale, test conditions, procedures for assessing casualties and system damage, departures from the test plan, and limitations of the test series.

C. SHOT SELECTION RATIONALE (U)

(U) The shot selection rationale of the Detailed Test Plans (Refs. 9 and 10) are important because it was from these that the specific test objectives were inferred. It is clear from the shot selection rationale that some shots served multiple objectives. The shot selection was complicated by the fact that shotlines were selected:

- at three different times
  - Phase I
  - Phase IIA (High Survivability test)
  - Phase IIB (ASTB test)
- according to three selection methodologies (described in Section B)
  - random (BAST)
  - repeat of previously tested shotlines
  - prescribed shots
- for six different vehicle configurations
- against five threat types.

(U) The shot selection rationale are addressed by test phase and vehicle configuration in the following eight sections. Table 11 summarizes the shot selection according to the three selection methodologies. Note that roughly two-thirds of the shots were randomly generated using the BAST recommended methodology.

Table 11. (U) Shot Selection Methodology

UNCLASSIFIED

Phase IIA	Random (BAST Method)	Repeat Phase I (Pairwise Comparison)	Prescribed	Total
M2		3 RPG-7G 1 TOW		4
M3	8[b] RPG-7G 2 30mm			10
M2 (HS)	1 RPG-7G 3[c] TOW 2	1 MINE[a]		5
M3 (HS)	8 RPG-7G 6 30mm 4[c] TOW 2 1 120 KE 1 120 HEAT	4 RPG-7G 2[d] 120 HEAT 1 TOW		27
Subtotals	34	12		46
Phase IIB				
M3 (ASTB)	8 RPG-7G 6 30mm 1 TOW 2 1 120 HEAT		3 RPG-7G 1 30mm	20
M2 (ASTB)	1 RPG-7G	1 MINE[a]	4 RPG-7G 1 30mm burst[e]	7
M2 (HS)			2 RPG-7G	2
M3			2 30mm burst[e]	2
Subtotals	17	1		31
Totals	51	13	13	77

[a] Mine shots (TMN 46) were repeats of DT-II.
[b] One shot was repeated because the auxiliary water fire extinguisher system was accidentally discharged.
[c] Two of the TOW 2 shots were conceded (not shot) for the M3 (HS). The same shot lines were conceded for the M2 (HS).
[d] Two shotlines were selected, one of which was shot twice, with and without live fuzed stowed ammunition.
[e] Three-round bursts.

1. Phase IIA M3 (HS) (U)

(U) Twenty-seven shots were selected for firing against the M3(HS) vehicle.

a. Repeated Phase I Shots for Comparisons of M3(HS) (U)

(U) Seven of the ten Phase I shotlines against the Basic M3 were selected as repeat shotlines for comparative purposes. A statically detonated TOW round was not repeated (its dynamic counterpart from Phase I was one of the seven selected), nor were two RPG shots into areas not expected to show any differences between the Basic and HS vehicles.

b. BAST Methodology Random Shotlines (U)

(U) The other 20 shotlines were selected based on the BAST methodology to provide insights into crew casualty and other system vulnerability effects. Two of the BAST methodology TOW 2 shotlines were conceded as catastrophic losses with all crew lost. The OSD and the Army had agreed that shots could be conceded (not shot) if there was a physical basis for expecting a catastrophic loss, and if the shot would be counted for statistical purposes as though it had been assessed as catastrophic loss of vehicle with all crew casualties.

c. Direct Pairwise Comparison of M3(HS) and M3(B) (U)

(U) All 12 of the RPG shots selected as described above (8 BAST and 4 Phase I repeat) were intended for use in a direct pairwise comparison of the M3(HS) and M3(B) configurations against the RPG-7G threat. The Phase I repeat shots were expected to favor the HS configuration in that they were into areas affected by the survivability enhancements, while the BAST shots were randomly selected and therefore not expected to favor either configuration. (The eight BAST RPG-7G shotlines were also used for a direct pairwise comparison of the M3(B) and M3(ASTB) vehicles.)

2. Phase IIA Basic M3(U)

(U) Ten shots were selected for firing against the M3(B) vehicle.

a. Matched Random Shot Comparisons to M3(HS) and M3(ASTB) (U)

(U) As described above, the eight RPG-7G shots were intended to provide a direct pairwise comparison between the M3(B) and M3(HS) of the effects of RPG-7G

shots. (The same shotlines were used in Phase IIB against the M3(ASTB).) Four RPG-7G shotlines repeated from Phase I M3(B) testing were also available for additional pairwise comparisons of the M3 versus the M3(HS) permitting a direct pairwise compairson of the M3 and M3(HS) over twelve shots. The RPG was selected for a pairwise comparison because it is an overmatching weapon against which the M3(HS) enhancements were expected to reduce casualties. It was felt that the TOW 2 and 120mm threats might be so destructive to both vehicles that any differences might not be apparent. On the other hand, the 30mm rounds would not have provided a test of the reactive armor which was considered one of the most important of the HS enhancement features.

b. Armor Differences Between M3(B) and M3(HS) (U)

(U) The two 30mm shots were paired with two (of the six) Phase IIA M3(HS) shots for a comparison of the armors of these vehicles. One matched shot was selected to compare the effectiveness of reactive armor against a 30mm round to the Basic M3 armor against the same round. A second shot was selected to test the effectiveness of the high hard steel applique proposed as a survivability enhancement.

3. Phase IIA Basic M2(B): Casualty Differences Between M2(B) and M3(B) (U)

(U) A test issue not addressed in Phase I was crew casualty differences between the M2 (nine persons) and M3 (five persons). To address this issue, four shots into the crew compartment were selected for firing against the M2(B) in Phase IIA. These shotlines matched those from Phase I M3(B). (The same shotlines were also selected against the M3(HS).)

4. Phase IIA M2(HS) (U)

(U) Five shots were selected for firing against the M2(HS) in Phase IIA.

a. Casualty Differences Between M2(HS) and M3(HS) (U)

(U) As with the M2(B) shots, the primary issue was crew casualty differences between the M2 and M3 configurations. Thus, one RPG-7G and three TOW 2 shots, which were previously selected using the BAST methodology for Phase IIA tests of the M3(HS) and which met the criterion of a clear overmatch into the crew compartment, were selected for the M2(HS) vehicle. (Two of these TOW 2 shots had been conceded

against the M3(HS) under conditions previously described, and were also conceded against the M2(HS).)

b. Vulnerability to the TMN-46 Mine (U)

(U) The TMN-46 mine shot from developmental (DT-II) testing was selected as a repeat shot for additional data on the lethality of this weapon to the Bradley. The Materiel Need Statement for the Basic Bradley mentioned in the detailed test plan (Ref. 9) had specified that this weapon not cause a hull rupture when detonated three inches below the ground.

5. Phase IIB M3(ASTB) (U)

(U) Twenty shots were selected for firing against the M3(ASTB) in Phase IIB.

a. Comparison With M3(HS) Over BAST Shotlines (U)

(U) In order to directly compare the vulnerabilities of the M3(ASTB) with the M3(HS), 16 of the 20 BAST shotlines selected for M3(HS) Phase IIA testing were repeated against the M3(ASTB). Of the four shotlines not selected, three were TOW 2 shots and one was a 120mm shot. Two of the TOW 2 shots had been conceded (not shot) against the M3(HS). Although these shots were technically not conceded against the M3(ASTB) because they were never selected, the Phase IIB Test Plan (Ref. 10) stated that it was expected the results would have been similar because no significant differences existed between the vehicle configurations for those shotlines. The third TOW 2 shot was not selected because it was considered comparable to the selected TOW 2 shot. The unselected 120mm M3(HS) shotline had been conceded by the Army, and it was decided the shotline should not be tested against the ASTB because in that part of the vehicle there are no significant differences between the ASTB and HS vehicles.

b. Effectiveness of the ASTB Enhancements (U)

(U) Four shots were prescribed primarily to assess specific survivability enhancements of the ASTB not addressed by the randomly selected shots. Three of the shots were prescribed to assess the ability of the internal ammunition compartments to isolate the effects of 25mm ammunition reactions from the crew. A third shot was prescribed to assess crew protection from a hit between stowed TOW 2 missiles. The fourth shot was prescribed to assess the fire hazard from impacts on the external fuel cell and any synergistic interaction with the 25mm ammunition compartment.

6. Phase IIB M2(ASTB) (U)

a. Vulnerability to the TMN-46 Mine (U)

(U) The mine shot was a repeat of the mine shot in DT-II and in Phase IIA. It was selected so that this weapon would be tested against all three of the Bradley M2 design concepts.

b. Comparison of Crew Casualties Between M2 and M3 (U)

(U) One RPG-7G shotline was selected from among the M3(ASTB) BAST methodology shotlines to provide a comparison of crew casualties for that shotline. Selection was restricted to shots into areas where differences were expected between the M3(ASTB) and M2(ASTB), specifically the side and rear of the vehicle.

c. Effectiveness of Ceramic Armor Applique (U)

(U) Of the prescribed shots, the three-round 30mm burst was intended to assess the ballistic protection and multi-hit capability of the ceramic applique armor installed on the lower front glacis.

d. Effectiveness of Blowout Compartments (U)

(U) One of the RPG-7G shots was prescribed to assess the ability of the external TOW/25mm ammunition compartment to isolate the crew from the (worst case) effects of a TOW 2 flight motor detonation. A second RPG-7G shot into an externally stowed box of 25mm ammunition was intended to provide information on damage to the TOW launcher and structural effects from 25mm ammunition reactions.

e. Turret Damage Comparison With M2(HS) (U)

(U) The other two RPG-7G shots were prescribed to assess the effects of shots against the turret, primarily effects on crew and fire control componentry. These matched Phase IIB turret shots against the M2(HS).

7. Phase IIB M2(HS) (U)

a. Turret Damage Comparison With M2(ASTB) (U)

(U) The two RPG-7G shots were prescribed to impact the reactive armor tiles on the turret. These shots matched shots into the turret of the M2(ASTB), which lacks

reactive armor. In addition to providing a direct comparison for shots expected to favor the HS configuration, the shots were expected to provide needed information on shock damage to electro-optic components as well as effects on gun aiming alignment.

8. Phase IIB Basic M3 (U)

a. Adequacy of the AFSS Against Three-Round Bursts (U)

(U) Two 30mm, three-round bursts against the M3(B) were prescribed to assess the adequacy of the automatic fire suppression system (AFSS) given closely spaced (in time and dispersion) penetrations into the interior fuel cell.

D. TEST CONDITIONS (U)

(U) All target systems were fully combat loaded ("full-up") for the live fire test shots. In several respects the Army was testing a worst case scenario. All persons were assumed on board, even though some scenarios of the combined arms concept would call for the fire team (six squad members) to be dismounted from the M2 when the Bradley is likely to draw enemy fire. Fuel tanks were fully loaded at temperatures considered maximally realistic (desert fighting). A full complement of munitions was carried by all target vehicles, while a Bradley hit in combat would likely have expended some of its munitions.

(U) On the other hand, the fuzes for the stowed munitions were inert for all but one shot, though in all other respects the rounds were live. The inert fuzing was for safety reasons.

(U) For cost reasons, and consistent with the test plan, the Integrated Sight Unit (ISU) was removed for one M3(HS) shot for which major damage to the component was expected. The ISU was replaced with metal considered roughly equivalent in its ability to shield other components. The ISU was assessed as destroyed for this one shot. The ISU was also removed for another shot for which there was great risk of losing the vehicle. Other than noted above, the vehicles were totally combat configured from top to bottom.

(U) All shots were dynamically fired at simulated combat ranges, with the exception of some RPG-7G shots. Twelve of the RPG-7G shotlines had been selected for a direct pairwise comparison between the Basic and HS Bradley configurations. The delivery accuracy of the RPG-7G dynamically fired is considered very poor at combat

ranges. Hence performing pairwise comparison shots on identical impact points was not feasible for dynamically fired RPG-7Gs. Because vulnerabilities can vary considerably for impact points in close proximity, it was considered unwise to pair two dynamic RPG-7G shots unless it could be demonstrated that behind armor effects differed between static and dynamic RPG-7G shots. Offline tests indicated that differences were sufficiently minimal that static and dynamically launched RPG-7G shots could be paired. When static and dynamic shots were paired, the dynamic shot took place first, with the static shot matching the actual impact point on corresponding vehicles.

(U) The exact matching of impact points was considered most critical for the twelve shots paired for a direct comparison between the HS and Basic configurations. In case there did happen to be a difference in effects between static and dynamic shots, the following method in the test design ensured that neither vehicle configuration was favored. In four of the eight BAST shotlines the dynamic shot was launched against the HS configuration and in four other cases the dynamic shot was against the Basic configuration. The remaining four shotlines used for the direct pairwise comparison were repeats of Phase I dynamic shots against the M3(B). The matching M3(HS) shots were therefore statically detonated. The ASTB BAST shots that were to be compared with the HS shots were fired under the same test conditions as the HS. The prescribed "engineering" shots required specific hit locations and were thus statically detonated.

(U) As noted above, for four of the twelve shots used in the pairwise comparison of HS and Basic vehicles, the Basic shot had already taken place in Phase I. As a check on the comparability of Phase I and Phase II shots, velocities of the dynamic shots were compared. The average velocities were found to be equal (180m/sec) for both Phase I and for Phase II.

E. CASUALTY AND DAMAGE ASSESSMENTS (U)

(U) This section addresses the process of translating observed physical damage to assessments of loss of combat utility, and the role of assessor judgment in that process.

1. Damage Assessment Procedures (U)

(U) The Army damage assessment team recorded physical damage as soon as the site was considered safe, almost always within one or two hours of the shot. Although several assessors were present, no attempt was made to determine independence of judgment. Rather the assessors discussed the likely course of events among themselves

until a consensus could be reached. Representatives from OSD were on site during the assessments to ensure the validity of data collected and to determine how the assessors arrived at their conclusions. These representatives were also present during the data reviews. The role of judgment was most often an issue in casualty assessments and in shots involving fires. (These are discussed in later sections.) Operational tests conducted following the initial damage assessments were so thorough that judgment was essentially not an issue regarding vehicle subsystem damage.

2. Damage Measures and the Role of the Standard Damage Assessment List (SDAL) (U)

(U) The damage assessment team was responsible not only for recording physical damage, but for converting damage to loss of combat utility using four numeric measures: crew casualties, M-kill (fractional mobility loss), F-kill (fractional firepower loss), and K-kill (catastrophic loss). These measures are not independent of each other. In particular, crew casualties enter into the system kill measures (M, F and K) via the Standard Damage Assessment List (SDAL) (Ref. 6). The SDAL (see Table 12) is a list of "critical" components, i.e. those contributing to loss of firepower or mobility, together with percentage loss of utility associated with each damaged component. (For this purpose certain crew members are considered as system components just as the engine would be.) Thus the assessment team, after determining which components were damaged, used the SDAL to combine the effects into a single number for each kill criterion. In using the SDAL one assumes independence of component effects except in the case of crew casualties, where the SDAL specifies system loss of function for each possible combination of crew casualties.

Table 12. (U) BFVS Standard Damage Assessment List

(~~CONFIDENTIAL~~ UNCLASSIFIED)

(U) Understanding the role of the SDAL is critical to understanding the summary statistics for the test. The assessment of physical damage is relatively free of judgment, except for the determination of casualties. However the transfer of that damage to a percent loss of function involves a great deal of judgment. Those judgments are incorporated in the SDAL. Documentation of the development of the SDAL for the Bradley has not been identified or made available to OSD, however it appears it was produced as a joint effort between the modeling and user communities.

(U) It is also important to understand the information lost in reducing damage assessments to measures of system kill. Once the reduction has been made to percent loss of function, such as 40% F-kill, one cannot distinguish from this measure alone whether that loss is due to crew casualties or from one or more of the other critical components. Casualty measures represent a similar loss of information. Once the assessments have been reduced to a single casualty number, one does not know how many persons were considered affected. The measure "crew casualties" represents "total fractional casualties," so that a crew casualty measure of 1.00 may represent one person totally incapacitated or two persons each with 50% incapacitation.

(U) Thus from the percent loss of function alone, one cannot determine whether a test resulted in a surprise without a list of components expected to be damaged versus components actually damaged. For the Bradley tests, model predictions were expressed only in terms of the three kill measures and in terms of casualties. From this information alone very little could be done relating to an analysis of the predictive capabilities of the models.

(U) Reduction of damage to loss of function (LOF) also obscures any damage to the "non-critical" components of the system, such as ammunition loss, loss of a fuel cell or loss of reactive armor protection. In particular the LOF measure would not include damage to the vehicle that might make it more vulnerable to subsequent shots, such as leaking fuel, damaged ammunition strewn through the vehicle or the loss of the AFSS system. Nor would the LOF measure reflect any degradation in swim capability or loss of NBC protection.

(U) For all the above reasons, the numbers produced through the SDAL transfer function are of limited utility in answering many questions about the vulnerabilities of the Bradley without the assessment team's report of physical damage.

3. Conceded Shots (U)

(U) The Army conceded four shots generated by BAST methodology as catastrophic losses. For analytic purposes, each of these shots was treated in the analyses as though it had been fired and the result had been scored a worst case: total M-, F- and K-kill and loss of all crew. These were the ground rules under which the Army was permitted to concede shots.

4. Casualty and Damage Criteria (U)

(U) The criterion for a crew casualty was "five minute assault," which means basically that a casualty is scored if, at any time within five minutes of the shot, the crew member is incapable of performing an assault mission. A person may be injured without being considered a casualty if he suffers no loss of combat capability (incapacitation) according to the casualty criterion. For example, eardrum rupture may be considered an injury, but a person with eardrum rupture alone was not considered a casualty. At the other extreme, no distinction was made between incapacitating injury and death. In some cases, the assessors assigned fractional casualty values to some crew members. These values represent the expected loss of combat capability when random elements and variability of human response to injury are considered.

(U) The system M-kill and F-kill kill criteria were based on the ability of the system to move and fight for ten minutes following the shot. The vehicle was required to leave the test site under its own power and to pass checks of the firepower system. The application of the mobility criterion required judgment in one case where it was determined that, through a minor repair that could be performed in the field within eight minutes, mobility could be regained. In this case, an 80% M-kill was assessed. On the other hand, if it was determined that damage would become apparent at any time within ten minutes that could not be repaired within that time period, a total M-kill was asessed.

(U) The K-kill criteria used for this test series was: 100% M-kill, 100% F-kill <u>and</u> an assessment that it was not economically feasible to repair the vehicle. In practice K-kills resulted from violent reactions which very quickly and irreversibly resulted in sympathetic reactions of stored combustibles. In such cases, no repairs were attempted. (The maximum reported time for hull and engine repair of a non-K-kill was 144 hours.)

(U) The assessment of a K-kill necessitated the scoring of 100% crew casualties, unless it was determined that crew members could have escaped any violent catastrophic reactions of stored combustibles. Because the interior of a test vehicle was always gutted after a K-kill, it was difficult in some cases to determine whether crew members were healthy enough and had the time to leave the vehicle. Judgment was required of the assessment team. For the three shots assessed as K-kill (not counting conceded shots), only one crew member was considered capable of exiting the vehicle and was therefore not considered a total casualty.

5. Assumptions About Crew Actions (U)

(U) For those shots resulting in slow developing fires, assumptions were made by the assessment team about crew response. In this regard the Army assumed a best-case scenario by assuming a well-trained crew motivated to stay with the vehicle and fight any fires unless a catastrophic loss was clearly unavoidable. In such cases the assessment team exercised judgment as to the crew's capabilities in fighting the fire and the probable extent of the damage had they done so. In 19 instances a slow developing fire occured which required fire fighting actions at the test site using equipment that would have been unavailable to the crew. On the other hand, a Bradley crew would have had available hand held (backup) extinguishing systems that could be directed to the source of the fire much more efficiently than the remote systems on the test site. Section II.G provides a full discussion of the assessments for these shots.

(U) The OSD representatives on site were in essential agreement regarding the crew's <u>capability</u> in these cases. There was some question, however, about the average crew's likelihood of staying with a vehicle in instances involving fire, especially when the vehicle sustained substantial loss of function. For instance in one case the assessors assumed the crew would stay with the vehicle to fight a fire even though all mobility and firepower function had been lost.

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6. Assessment of Crew Casualties (U)

(U) The methodology used by the assessors for converting spall and jet damage to the plywood mannequins into fractional casualties has existed for many years. This methodology does not distinguish between percent loss of function and probability of loss of function, but combines these into a measure that could be described as expected casualties. Nor does the methodology distinguish different kinds of casualty criteria, such as death. Thus in general it was not possible to determine how many crew members would have died from a given shot.

(U) Thermal, blast overpressure and optical radiation data were processed by the Surgeon General's office and compared with threshold levels to determine casualties. The Surgeon General's office also measured toxic gas concentrations for some shots (fully instrumented) and made a preliminary assessment of casualties from toxic effects. Translation data (acceleration in various directions) were collected from anthropomorphic dummies. The limitations of both anthropomorphic and plywood mannequins will be

discussed in a later section (Section II.G.2). In general, however, neither type of mannequin is capable of being used to determine all kinds of anticipated damage mechanisms. Thus the casualty assessments must be viewed as lower bounds; they do not include either unanticipated damage mechanisms nor damage mechanisms incapable of assessment for a given mannequin. Section II.G addresses the differences between assessed and potential casualties.

(U) In converting the toxic gas data to casualty assessments, the Surgeon General's office assumed 30-second masking, based its assessments on short term effect data, and assumed the crew was in a state of activity both before and after the shot (high rate of inhalation). The 30-second masking criterion was considered a "worst-case" scenario in that within 30 seconds a crew member would either be able to put on his mask or leave the vehicle. (Troops are trained for nine-second masking.)

(U) The Surgeon General's office also calculated casualty results under other assumptions: delayed masking and long term effects. Section II.G examines the sensitivity of results to these alternate assumptions.

F. DEPARTURES FROM THE TEST PLAN (U)

(U) In general the test plan was very closely adhered to. Any deviations from the test plan were done with the concurrence of the OSD Live Fire Test office. Most notable were the addition of a shot against the HS vehicle, revision of the blast criterion for evaluating crew casualties and the "full" instrumentation of some shots listed in the test plan as "partially" instrumented. The shot added was an 120mm shot where the 25mm ammunition of the target Bradley was inert fuzed. This was added to match an 120mm shot against a live fuzed Bradley. The revision in the blast criterion reflected recent research into complex blast effects in enclosed containers. The Lovelace criterion of the test plan had been based on the effects of overpressures normal to the incident surface and in an open environment.

G. LIMITATIONS (U)

(U) It is never possible to measure all contributors to system vulnerability. This is especially the case for human effects, since a destructive test must use mannequins. It is also the case for system damage given the limitations of the instrumentation employed. The following sections summarize the limitations of this test.

1. Limitations to Assessments of Crew Casualty (U)

U) Two kinds of mannequins were used for the test series: plywood and anthropomorphic. Each had its limitations. The plywood mannequins were primarily used for crew positions where the primary casualty mechanisms were expected to be the kinetic energy of the main penetrator and associated spall. No attempt was made to assess crew casualties based on acceleration effects to these mannequins. In particular, if mannequins were broken at their hinges or if there were dents or other evidence of impact from stowed items, the damage was listed as "unknown," unless a casualty could be assessed based on acceleration data from an adjacent anthropomorphic dummy. In cases of catastrophic loss of the vehicle, all mannequins were consumed so no evidence of spall was available. The assessors did not know what damage the crew members would have suffered from spall and whether they would have been able to leave the vehicle. In such cases, the spall damage was listed as "unknown." Thus in general the casualty assessments represent only damage known (i.e., quantifiable) to the assessors using standard methodologies. (See Section II.G for sensitivity of results to assessor judgment.)

(U) The casualty information from anthropomorphic dummies was also limited. No methodology was available to assess casualties based on spall damage. Thus spall damage to anthropomorphic dummies was typically assessed as "unknown." In general anthropomorphic dummies were placed where they were not expected to receive spall damage, but such instances did occur. The analysis of the potential error from "unknown" damage is addressed in Section II.G.

(U) For some shots there was evidence of battery acid on crew members. No methodology is available to quantify such damage in terms of crew casualties. (No incremental casualties would have been assessed in these cases because the crew members were assessed as casualties from other mechanisms.)

(U) Finally, not all shots were "fully instrumented." Fully instrumented shots were those instrumented by the Surgeon General's office to collect information on overpressure, toxic fumes, thermal/optical radiation effects and shock levels. For partially instrumented shots, some of these kinds of data were not available for casualty assessments. Even for the fully instrumented shots, data were occasionally lost due to faulty data channels or damage to the channels from the shot effects. In addition, the instrumentation was neither adequate to determine the potential debilitating effects of

pain or stress on crew performance, nor any psychological effects that might affect the crew's motivation to stay with the vehicle.

(U) The effect of each of the above limitations is a potential reduction in assessed casualties. In other words the casualty assessments represent a lower bound. Section II.G attempts to quantify the potential error from "unknown" damage.

2. Limitations to Assessments of System Damage (U)

(U) The primary limitation to the assessment of system damage, other than the contribution of crew casualties to system degradation according to the SDAL, is the unknown damage associated with slow developing fires. In such cases the assessors were forced to make judgments based on the video cameras and post-shot examination of the vehicle whether the crew members could have extinguished the fire, and to determine the extent of the system damage had the crew been successful in such efforts. The analysis section attempts to quantify the potential error from these judgments.

II. TEST RESULTS AND ANALYSES (U)

(U) The full-up tests of the Bradley Fighting Vehicle were not designed to give an unbiased estimate of the vulnerability of the various vehicle configurations when averaged over all shots. Nor can all shots be used to compare the relative merits of each pair of configurations. Rather, various sets of shots were selected to answer specific questions, as summarized in the Shot Selection Rationale section. Because of the dynamic nature of many of the firings to assure test realism, it was considered likely that some of the shots would miss their aimpoints. Therefore the reporting of results and conclusions, while organized around the specific objectives, reflects whatever analyses were possible from the test data regarding crew casualties, the vulnerabilities of the tested vehicles, and the effectiveness of the survivability enhancements. This section summarizes the results according to four basic categories: general results, vehicle comparisons built into the shot selection rationale, results of prescribed shots addressing engineering issues, comparison of results with computer model predictions, and results related to other issues.

(U) Determination of the statistical significance of the live fire test results is based on the sign test. This nonparametric test was applied since there is no assurance that the underlying distributions of damage measures are normally distributed, and also because the sign test was approved by the Army and OSD for analysis of paired shots (Ref. 9)[1]. The criterion applied for application of the sign test was that the sample size consist of three or more shot pairs with at least one non-zero measure of damage and that non-zero ties (discarded by the sign test) not exceed 20 percent of the sample size[2]. The minimum of three shot pairs corresponds to a statistical significance level of 75 percent for a two-sided test given no sign changes among the sample pairs.

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[1] (U) Approval was for analysis of the paired RPG-7G shots between the HS and Basic vehicles. The analyses for which the sign test was used in this section are for the same kind of paired shot comparisons.

[2] (U) This roughly corresponds to the criterion suggested by Ref. 13.

A. GENERAL RESULTS (U)

1. Relative Vulnerabilities of the HS, ASTB and Basic Bradley Vehicles (U)

(U) Table 13 summarizes the results of the test firings by threat against the various Bradley configurations. The BAST shots are listed separately since they were randomly drawn from a distribution of shotlines to approximate what might be expected in combat.

Table 13. (U) Summary of Results Based on Full-up Live Fire Shots Conducted in Phases I, IIA and IIB, and on a Mine Shot From DT-II

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(U) It is noted that the overall level of casualties and damage is roughly the same over all shots as for the BAST (random) shots. This indicates that the prescribed shots, while of special interest because of the information to be obtained, do not appear in this case to bias the overall impression of the Bradley vulnerabilities.

a. RPG-7G Threat (U)

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b. 30mm KE Threat (U)

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c. TOW, TOW 2 and 120mm Threats (U)

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d. Results of BAST Shots Against the M3(HS) Vehicle (U)

(U) All 20 BAST shotlines were initially selected for use in M3(HS) Phase IIA testing. Some of these were then applied to other vehicles to permit vehicle comparisons, but in addition the BAST shotlines were intended to provide insights into crew casualty effects based on "a reasonable test distribution of four threat weapons" (Ref. 2): 30mm APDS, RPG-7G, 120mm KE/HEAT, and TOW 2. Table 14 summarizes the results of the 20 BAST M3(HS) shots.

Table 14. (U) Results of Twenty Phase IIA BAST Shots for Providing Insight Into M3(HS) Crew Casualty Effects Based on "...a Reasonable Test Distribution of Four Threat Weapons" (Ref. 9)

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2. Casualty Sources (U)

(U) Until recently both vulnerability models and assessment procedures reflected the fact that perforation (directly from the round or from its associated spall), fire and catastrophic explosion were considered the main casualty and damage producing mechanisms. Partly because certain vulnerability reduction design features may have increased the likelihood of a crew member surviving and having the option of staying with a damaged vehicle, and partly because the testing of more realistically configured targets with sophisticated instrumentation enables such questions to be addressed, more interest has been placed on other potential hazards to the crew including blast overpressures, acceleration, intense light and toxic fumes.

(U) The instrumentation and methodologies used for the Bradley Live Fire Test represented a significant advance in the ability to accurately assess damage from fire and the crew hazards noted above. It is important to determine whether these potential casualty producing mechanisms are significant contributors so that test programs can determine how important it is to measure for such effects, and so that modelers can determine how important it is to understand such phenomena and how much detail to incorporate into the vulnerability models.

(U) Table 15 summarizes the casualties in the Phase II Bradley full-up tests by type of vehicle and source of incapacitation. Where more than one source contributed to an incapacitation (redundant "kills") the total for a given individual may be greater than one casualty. This was necessary to determine the relative contribution of each casualty source.

Table 15. (U) Distribution of Assessed Casualties by Type of Vehicle and Source of Incapacitation

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3. Major Sources of System Vulnerability (U)

(U) With a limited number of live fire test shots, it is difficult to assess the overall vulnerability of the Bradley. However the test shots should reveal the major sources of vulnerability. An analysis was performed for each configuration and threat munition to determine which components or subsystems were implicated in shots producing loss of mobility or firepower. All Bradley shots were selected for this analysis, including Phase I shots. Table 16 summarizes the results for mobility loss, and Table 17 for firepower loss. No account was made of redundant losses of function. For example if both the engine and transmission were damaged on a given shot, the mobility loss tabular entries for both engine and transmission were incremented by one.

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Table 16. (U) Total Subsystem Contribution to Assessed Loss of Mobility Function

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Table 17. (U) Total Subsystem Contribution to Assessed Loss of Firepower Function

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B. VEHICLE COMPARISONS (U)

1. Test of M3(HS) Enhancements via Paired Shots Into the M3(HS) and M3 Basic (U)

(U) Seven of the Phase I shotlines against the M3(B) were selected to be repeated in Phase IIA against the M3(HS). These were the shotlines into areas where the M3(HS) was expected to show reduced vulnerability versus the M3(B) because of the survivability enhancement features. The breakdown by threat weapon was: four RPG-7, two 120mm HEAT and one TOW. One of the 120mm HEAT shotlines had been used twice against the M3(HS), once with inert fuzing of live stowed 25mm ammunition and once with live fuzed 25mm ammunition. The live fuzed shot was used for this comparison, because the 120mm warhead had malfunctioned for the inert fuzed shot.

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Table 18. (U) Results of Seven Phase I Shots Repeated in Phase IIA for Comparison of M3(HS) and M3(B) Vehicles

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2. RPG Shots Selected for Pairwise Comparison of M3 Basic and M3(HS) Vehicles (U)

(U) Twelve shots were selected for a direct pairwise comparison of the vulnerabilities of the M3 Basic and M3(HS) configurations to the RPG-7G shoulder

launched HEAT weapon. Eight of these were BAST shots while four were selected from the Phase I shotlines.

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Table 19. (U) Results of Twelve Paired RPG-7G Shots for Direct Pairwise Comparison of M3(HS) and M3(B) Vehicles

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3. Comparison of M3 Configurations Across RPG Shots (U)

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Table 20. (U) Eight BAST RPG-7G Shots Matched for Comparison of Vulnerability and Casualty Differences Among M3(ASTB), MS(HS) and M3(B) Vehicles

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4. Comparison of M3(HS) and M3(ASTB) Across Paired Shots (U)

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Table 21. (U) Results of Eight Phase IIB BAST Shots Paired with Phase IIA for Comparison of Vulnerability and Casualty Differences Between MS(ASTB) and M3(HS) Vehicles

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5. Paired Shots for Comparison of Crew Casualties Between M2 and M3 Vehicles (U)

(U) Nine paired shots were selected for comparison of crew casualties between the M2 and M3 vehicles based on overmatching weapons. Table 22 summarizes the results.

Table 22. (U) Comparison of Crew Casualties Between M2 and M3 Vehicles (B, HS and ASTB) Based on Overmatching Weapons

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Table 23. (U) Statistical Comparisons of M2 and M3 Casualty Levels

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6. Comparison of M2 Configurations Across Mine Shots (U)

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Table 24. (U) Comparison of TMN-46 Mine Shot Effects on M2(B), M2(HS) and M2(ASTB) Vehicles

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7. RPG-7G Turret Shots Selected for Pairwise Comparison of M2(HS) and M2(ASTB) Vehicles (U)

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Table 25. (U) Two Paired RPG-7G Turret Shots for Comparison of M2(ASTB) and M2(HS) Vehicles

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8. Paired 30mm KE Shots for Check Comparison of Armor Between the M3 Basic and M3(HS) Vehicles (U)

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Table 26. (U) Two Paired 30mm KE Shots for Check Comparison of Armor Between M3(HS) and M3(B) Vehicles

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C. RESULTS OF PRESCRIBED ENGINEERING SHOTS (U)

1. Relative Effects of Live Fuzed vs. Inert Fuzed Stowed 25mm Ammunition (U)

(U) The issue of testing targets stowed with live ammunition with live fuzes is important and goes beyond questions of test realism, cost and scheduling. Current Army explosive ordnance safety procedures restrict any test personnel from entering such a target for post-shot vulnerability assessments if live fuzes are used. Although the hazards to test personnel caused by the live fuzing of 25mm HEI-T ammunition were considered minimal both in terms of likelihood and level of severity, any possibility of injury to test personnel is considered unacceptable. (The explosive material in a 25mm HEI-T fuze is about the size of a watch battery, and contributes less than one percent of the explosive content. Further, the fuze is designed sc that when unarmed, as it is when combat stowed, the fuze will not initiate the rest of the round even if the fuze tip is damaged or burns. If the 25mm round is APDS, as are roughly one-fourth of the 25mm rounds carried on the Bradley, there is no warhead or fuze.)

(U) The safety procedures are considered appropriate. However, the question arises as to the relative tradeoff between a limited damage assessment when the live stowed ammunition contains live fuzes, versus a full damage assessment when the live stowed ammunition contains inert fuzes. This question cannot be adequately addressed

unless one determines both the magnitude of and conditions for any differences in effects when ammunition is stowed either way.

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Table 27. (U) Results of Matched 120mm HEAT Shot (300•, 900m) for Comparison of Results With and Without Live Fuzed Ammunition

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(U) The results of off-line tests addressing this issue were similarly inconclusive, because of both the limited number of firings devoted to this issue as well as firings that did not impact their intended locations due to dispersion induced by dynamic firing of the RPG-7G munitions.

(U) Although the full-up test and off-line tests alone were considered inconclusive, additional tests (Ref. 11) showed virtually no difference in the likelihood of sympathetic detonation to adjoining rounds whether the 25mm HEI-T test rounds were live fuzed or inert fuzed. Further, the design of the fuze was considered to preclude the possibility of a difference in effects. Therefore, additional tests were not considered necessary in this case.

2. Effectiveness of Vulnerability Reduction Features of the ASTB Vehicles (U)

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Table 28. (U) Results of Nine Engineering Assessment Shots for Evaluation of Specific Concerns Regarding the Design of M3(ASTB), M2(ASTB) and M3(B)

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(U) Engineering shots against the M2(ASTB) were a more severe test of the capability of the ASTB to protect the crew from ammunition reactions than the M3(ASTB) shots. Table 28 summarizes the results.

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3. Effect of 30mm APDS Bursts into Fuel Cell (U)

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D. ISSUES ADDRESSED BY OFFLINE TESTS (U)

(U) In addition to the primary Bradley Phase II full-up vehicle firings, Phase IIA also included six off-line subtests. These were conducted for two reasons, viz to examine and/or demonstrate the effect of proposed survivability enhancements and to provide supplementary information to the full-up tests. Table 29 lists the six subtests and summarizes their specific objectives.

(U) This section describes what was found in each of the subtests relative to the objectives of Table 29, together with comments regarding the robustness of the findings. The data and assessments presented here are based solely on information provided in the Volume 1, Appendix J report provided to OSD by the Army (Ref. 14).

(U) As a general observation, it is apparent that the offline tests are very useful in obtaining supplementary vulnerability data and insights into weapons effects. They can permit data gathering methods (such as the use of witness packs) which would be artificial intrusions into full-up tests, and in general they permit larger samples to be collected. This said, nevertheless, the sample sizes for a number of the offline tests reviewed here were still small in view of the many target combinations of interest which were explored.

Table 29. (U) Bradley Phase IIA Off-Line Subtests

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Subtest	Objectives
1. 25mm Ammunition Compartmentation	a. Determine level of crew protection offered by stowing 25mm ammunition in a separate compartment designed to vent gases from ammunition reaction to the atmosphere. b. Provide basis for design of 25mm compartment in the Advanced Survivability Test Bed.
2. 25mm Ammunition Reaction	a. Determine level of reaction of stowed 25mm ammunition to shaped charge jet degraded by High Survivability (HS) hybrid armor containing reactive armor (RA) tiles. b. Collect environmental crew hazards data for use by the Office of the Surgeon General from tests of overmatching shaped charges into stowed 25mm ammunition.
3. Halon Interactions	a. Determine Bradley crew environment when a TOW jet generated fuel cell fire is suppressed by the on-board Halon Automatic Fire Suppression System (AFSS). b. Determine environment due to interaction of Halon 1301 with self-extinguishing small arms amunition fire. c. For both the above, to provide data to the Office of the Surgeon General for complete analysis and use in ongoing research programs. d. Determine concentrations of neat Halon 1301 in Basic Bradley caused by AFSS discharge under various ventilation conditions.
4. Behind Armor Debris (BAD)	To fill some existing data gaps, viz. a. On behind armor debris (BAD) from shaped charge jet penetrations of aluminum armors. b. On a modern ATGM such as the TOW 2 vs. the Basic Bradley armor or vs. the reactive armor configurations proposed for the HS Bradley. c. On the ability of spall liners, in conjunction with various Bradley armor configurations, to suppress BAD for modern ATGMs.
5. Ready Box Vulnerability	To determine reaction of 25mm ammunition, stowed in ready box, to threat shaped charge jets fired through either the Basic Bradley or HS Bradley armor.
6. Live Versus Inert Fuzed 25mm HEI-T	To observe the frequency and "level of violence" of live fuzed 25mm HEI-T reactions initiated by RPG-7G attacks and to compare results with previous firings against inert-fuzed rounds. The purpose is to test the prior hypothesis that there is no appreciable difference in reactions between live and inert fuzed 25mm HEI-T rounds.

(U) It is noted that in many instances in these offline tests the intended target point was not hit and the shot was essentially lost insofar as the particular test objectives were concerned. This was particularly true for dynamic firings of the RPG-7G. Since the terminal ballistic differences between a dynamic and static firing of this shaped charge warhead have been shown to be minimal, it is suggested that more efficient acquisition of engineering test data would be obtained with static tests and that static firings be used for any future engineering test firings of the RPG-7G.

1. Offline Subtest 1: 25mm Ammunition Compartmentation (U)

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2. Offline Subtest 2: 25mm Ammunition Reaction (U)

(U) Four TOW and four TOW 2 missiles were fired into boxes of 25mm ammunition (either APDS or HEI-T). Pre-production side reactive armor tiles were used and the firings were at 60° or 0° obliquity relative to the reactive tile face, all in the horizontal plane. There were five shots at 0° obliquity and three at 60° obliquity.

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(U) The test objectives were addressed and met in this off-line test series. However since interest centered on the effect of overmatching jets degraded by reactive armor it would have been more appropriate to have had fewer 0° obliquity shots and some at intermediary obliquities such as 30°. The test results give no indication whether the results of such firings would be more similar to the 0° firings or the 60° firings.

3. Offline Subtest 3: Halon Interactions (U)

(U) This test consisted of five TOW shots into the upper fuel cell to provide data on Halon concentrations resulting from the AFSS activation to extinguish fuel fires, and three RPG-7G shots into stored ammunition to examine Halon concentrations for ammunition fires. Instrumentation data were provided to the Office of the Surgeon General for analysis.

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4. Offline Subtest 4: Behind Armor Debris (BAD) (U)

(U) This test used nine different target configurations representing combinations of frontal and side armor, Basic and High Survivability Bradley configurations, with and without reactive armor, with and without spall liner, and (when spall liners were used) for both four inch and zero inch liner offsets. Thirty-nine TOW 2 missiles were fired, with BAD data collected using witness packs. The firings were conducted at obliquities of 0°, 30° and 60°.

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5. Offline Subtest 5: Ready Box Vulnerability (U)

(U) Five shots (two RPG-7G, two TOW and one TOW 2) were fired against 25mm ammunition in ready boxes in component level mockups of either the current Basic Bradley armor (RPG-7G shots) or the HS Bradley with reactive armor (TOW and TOW 2 shots). One of the RPG-7G shots missed the ready box and was not repeated due to shortage of test missiles.

(U) It can be concluded from these tests, relative to the test objective, that 25mm ammunition in the ready box can react violently to the RPG-7G when the ready box is in the Basic Bradley, and to either the TOW or TOW 2 when the ready box is in the HS Bradley. However, too few rounds were fired to warrant any good estimate of the extent or precise nature of the reaction.

6. Offline Subtest 6: Live versus Inert Fuzed 25mm HEI-T (U)

(U) In this test a box containing 30 rounds of live 25mm HEI-T ammunition with live fuzes was placed inside a compartment whose front wall simulated Basic Bradley armor. Three dynamic RPG-7G firings were made for comparison with previous tests using live 25mm HEI-T ammunition with inert fuzes. Because the RPG-7Gs were dynamically fired, not all shots hit their aimipoint. One was recorded as a hit on the center of the box, while the other two were each recorded as a "near miss."

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(U) In view of the sample size of one direct hit and the uncertainty regarding the status of the "missing" rounds, the statement in the report, that the results of this subtest were comparable to those observed in earlier firings into and near inert fuzed ammunition, is not supported by the presented data. With but one shot directly into the 25mm HEI-T ammunition with live fuzes, it cannot be said that this test met its objectives. Specifically, no valid judgment can be made, based on the reported observed damage or numerical results, that there is no appreciable difference in reactions between live and inert fuzed 25mm HEI-T ammunition.

E. PREDICTIVE CAPABILITY OF THE MODELS (U)

(U) Although M-, F-, K-kill and expected casualty predictions were made for each Phase II shot and were included in the Detailed Test Plans (Refs. 9 and 10), no documentation was provided on the models which produced the predictions. Accordingly, it is only possible to compare the given model outputs with assessed test results.

(U) The following analysis is based on the data provided to date, as reported in the Army Phase II Live Fire Test Report (Ref. 10). Because the model was changed as a result of the Phase IIA test, the Phase IIA model must be treated as different from the Phase IIB model. Further, the computer model used for pre-shot predictions was not applied to the actual shotlines tested as required by the Detailed Test Plan (Ref. 7, Vol. V, p. V-9), and the model upgraded as the result of testing was not applied to the shotlines for which predictions were made. (See Table 30.) Therefore, analysis of the performance of the vulnerability model must be considered preliminary.

Table 30. (U) Data for Analysis of Model Predictions

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	Predicted Impact 4" Cell	Actual Impact 4" Cell	Actual Hitpoint
Phase II Pretest [a] Model	X	X	
Post Test Updated Model			X
Assessed Live Fire Test Result			X

[a] Phase IIB predictions based on model changed as a result of Phase IIA tests.

1. Predictions of Expected Casualties, M-kill, F-kill and K-kill (U) (U)

(U) Users of the models are most interested in the output measures of casualties, M-, F- and K-kill. Table 31 summarizes the "predictions" versus results for these measures in Phase II testing. It was considered most appropriate to compare the model predictions with test results over a set of shots, rather than on a shot-by-shot basis, because the vulnerability model used for predictions bases its output to some extent on expected averages over large numbers of shots. This feature limits its usefulness for live fire tests with relatively small sample sizes. Results from the upgraded model should not be considered truly predictive since the model was modified to reflect some results of Phase II testing. The original Phase II model results shown in the two bottom rows of Table 31 can be considered predictive. Unfortunately, however, these predictions were not adjusted to reflect actual impact points. Thus, it is not possible to obtain a true comparison of the predictive capabilities of the models. Table 30 illustrates the problem of performing a comparison of model "predictions" with test results.

Table 31. (U) Comparison of Live Fire Test Results with Mobility, Firepower and Casualty Results of Vulnerability Models (Averaged over 72 Shots for All Vehicle/Threat Weapon Types)

(~~SECRET~~ UNCLASSIFIED)

(U) Nonetheless, the results shown in Table 31 appear to indicate that the models tended to underestimate damage effects for the three measures (M-kill, F-kill and expected casualties). The differences, however, are not statistically significant except for expected casualty predictions by the pretest Phase II models.

(U) The vulnerability model used for preshot predictions did not have the capability to account for the variety of possible damage states over repeated shots into the same impact point. Rather, the model employed by the Army for its "predictions" produced one overall estimte of the average of expected results. This average result may never occur for any single shot. Therefore, the following represents only a cursory analysis of the predictive capability of the models on a shot-by-shot basis.

(U) Table 32 summarizes the differences ("errors") between each model prediction and its corresponding test result As noted above, when averaged over all shots, the predictive "errors" counterbalance each other so that there is very little difference on average between any of the model predictions and the test results. However, the standard deviations are rather large, indicating that deviations from the predicted results were substantial for some shots.

Table 32. (U) Summary of Model Differences From Live Fire Test Results

(~~SECRET~~ UNCLASSIFIED)

(U) To explore this matter further, an (arbitrary) criterion was applied, that a prediction is "incorrect" when the magnitude of the difference between model prediction and test result is 0.30 or greater. By this criterion, the percent of shot predictions considered "incorrect" is 27 percent, 25 percent and 16 percent, respectively, for the measures M-kill, F-kill, and proportion of expected casualties.

(U) In an attempt to determine how well the updated model is able to represent the vulnerability of specific Bradley configurations to specific types of threat weapons, selected combinations were analyzed. Results are summarized in Table 33. Although the updated model overestimated RPG-7G effects against the M3(HS) and possibly the M3(B), it underestimated the effects of the larger caliber weapons (i.e., 120 HEAT, TOW and TOW 2) by 30 percent to 53 percent. The latter effects are shown to be statistically significant for F-kill and expected casualty estimations. The underestimation of expected casualties was by nearly one person per shot when averaged over the seven large caliber firings against the M3(HS). It must be remembered that these comparisons are based on shots whose results were used to upgrade the model. It is not known how well the upgraded model would predict results over a large sample of untested shot conditions.

Table 33. (U) Comparison of Mobility, Firepower and Casualty Results Between Live Fire Testing and the Updated Vulnerability Model for Selected Threat Weapon/Vehicle Combinations

(~~SECRET~~ UNCLASSIFIED)

2. Component Level Predictions (U)

(U) As indicated earlier, very different combinations of component loss can result in similar assessments of loss of function. Even though users of the models may primarily be interested in reduction to percent loss of function, it is important to designers and others that the model accurately predict the kind and severity of damage suffered by the vehicle for a given shot. For such an analysis, one would need at least the predicted damaged components for each shot. These predictions were not available for this analysis.

F. VULNERABILITIES TO SUBSEQUENT HITS (U)

(U) The primary interest in the vehicle vulnerability analyses was loss of the combat functions of firepower and mobility. It is for these combat functions that physical damage was reduced to fractional losses.

(U) However, it is also important to consider any degradation in vehicle protection resulting from a hit. To some extent this is reflected in the M-kill and F-kill numbers. Clearly if a vehicle has lost mobility it is more susceptible to future hits. Similarly, if a vehicle has lost firepower it has lost the ability to neutralize enemy systems before they can get off a shot. The implications of these losses can be determined by applying these results to the operational test and evaluation.

(U) Other live fire damage to vehicles that could be factored into the operational test and evaluation is the loss in swim capability resulting from a hit by threat weapons. While no assessment was made of loss of swim capability (swimmability), it must be assumed that any penetration of the hull would result in loss of swimmability. What is not known is the loss of swimmability resulting from non-penetrating shots, particularly those stopped by the reactive armor.

(~~S~~ U) ....

Table 34. (U) Sources of Increased Vulnerability to Subsequent Hits

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G. SENSITIVITY OF RESULTS TO ASSESSOR JUDGMENT, ASSUMPTIONS AND DEFINITIONS U)

1. Crew Response to Fire (U)

(U) Since fires resulting from shots against the vehicle have the potential to result in catastrophic loss, the assessment of the likely outcome of any fire is very important in establishing the vulnerabilities of the tested vehicles. The assessment of the likely outcome of fires, however, suffers from two major difficulties. First, crew response to shots resulting in fire is likely to be unpredictable and highly variable. Second, even if the crew is assumed motivated to stay with the vehicle and fight a fire, it is difficult to determine the crew's capability to fight a fire. Crew awareness of the fire and potential to fight the fire can only be estimated by assessors based on the video and thermocouple evidence, and the effectiveness of test personnel in fighting the fire. In general, crew members would have the advantage in more quickly identifying a fire source and having the potential to jettison smoldering objects or to direct hand held extinguishers at the source of the fire. On the other hand the backup Halon, carbon dioxide and water systems at the test site would not be available to the crew.

(U) The problem for the assessors, then, was how to deal with the problem of what the crew <u>could</u> and <u>would</u> do in any given instance. As to the crew's potential to fight a fire, the assessors exercised judgment by evaluating the data available from cameras, thermocouples and a post-shot inspection of the vehicle. In the absence of knowledge concerning the psychological reactions of the crew, the assessors applied a clearly defined criterion of a "motivated" crew. The assumption was that any non-injured crew members would make every effort to save the vehicle unless it was clear that a catastrophic loss was unavoidable. This is perhaps optimistic given reports of armored crew response to fires in Vietnam (Ref. 15). In some of the reports, it appeared that crew members in Vietnam exited the vehicle when hit and later made decisions as to whether to attempt to fight any fires.

(U) The results are summarized in Table 35, which includes only those instances where actions were taken by test personnel. Thus the table does not include either self-extinguishing fires or any catastrophic losses where no attempt was made to extinguish the fire. Because of the information available to the assessors for this test series, little doubt existed for many shots as to the likely course of events had the crew attempted to extinguish fires. When reasonable doubt existed, however, the assessors tended to be conservative (estimate damage on the low end of the possible) with respect to what the crew could and would do. For example, the test plan says that the "carbon dioxide and Halon systems will be discharged initially for a period of ten seconds to permit an assessment of whether on-board portable extinguishers would be capable of extinguishing the fire." In fact, catastrophic kills were only assessed when test personnel could not control the fire or could barely control the fire using any of the resources available to them, i.e., by completely filling the vehicle with water. In one case, no K-kill was assessed even though the vehicle was filled with water.

Table 35. (U) Judgments Related to Fire Assessments

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(U) As examples of the kind of assessments resulting from assuming a "motivated" crew, there were two cases where a complete loss of mobility and fire power was assessed, yet it was presumed the crew would have stayed with the vehicle to fight fires and prevent a catastrophic loss.

(~~C~~ U) ....

(U) In summary, it appears more evidence is needed of likely crew response. Possibly historical data can be used for more realistic assessments. In addition, there is the need to train crew members as to what they can do to fight fires, and under what circumstances it is best to stay with the vehicle.

2. Judgments Regarding Casualty Assessments (U)

(U) Because testing is conducted with mannequins rather than live humans, the assessors must convert available information to level of incapacitation by some means. Methodologies have been developed to convert data to casualties for penetrator and spall damage to plywood mannequins, acceleration data from anthropomorphic mannequins, overpressure and thermal data, and toxic gas data.

(U) On the other hand, assessors had to make judgments regarding casualties when data were missing, data were contaminated or where no standard methodology existed to convert data to casualties. Examples of missing data included lost data channels and burnt mannequins. Contaminated data included instances where test instrumentation or a surrogate component provided unrealistic shielding to mannequins. An example of non-existent methodologies included the conversion to level of incapacitation of spall damage to anthropomorphic dummies.

(U) In general, where assessors could not confidently quantify damage, no incremental incapacitation was assessed. While there is a technical difference between an assessment of no damage and "unknown" damage, the net result remains that in both cases no additional casualties are assessed.

(U) Table 36 summarizes those instances where the assessors had to exercise significant judgment in assessing casualties. An attempt was made to estimate as an upper bound the potential casualties at issue for those cases. This was calculated as 1-(assessed incapacitation) for each crew position affected. The calculation does not include those instances where data channels were lost. It should be emphasized that the computation of an upper bound for incremental casualties does not reflect potential disagreement with assessed values, simply because the assessors chose not to assign a value in most of the cited cases. Nor does it indicate the most likely level of incremental incapacitation. In some cases, it is almost certian there would have been no incremental casualties, in other cases there was almost certain to be incremental casualties but the level could not be confidently determined.

Table 36. (U) Judgement Related to Casualty Assessments

(~~CONFIDENTIAL~~ UNCLASSIFIED)

(U) Table 36 indicates that the major categories of assessor judgment were: impact from debris, spall damage to anthropomorphic dummies, and spall damage to plywood mannequins consumed by fires which assessors ruled the crew could have escaped or extinguished. The maximal potential increase in casualty assessments due to assessor judgment was 13.82. (As noted above, this shoud not be interpreted as an estimate of assessor error.) This number is not great in relation to the total number of crew for which casualty assessments could be confidently made. Furthermore, it is difficult to see how the exercise of judgment could have been avoided. The issue, rather,

appears to be whether it is better to make an informed judgment likely to have some error or to assess the level of damage as "unknown" (no value assigned). Both approaches were taken for this test series. (Examples of the former approach are the estimate of spall damage to the anthropomorphic dummy of shot M3(HS) 22, and the assessment of toxic effects for four shots by comparison with similar shots. An example of the latter approach is the listing of spall damage to the anthropomorphic dummy of shot M3(HS) 24 as "unknown.") In general, for this kind of report, it seems better to make an informed judgment even if it is likely to be in error, because there is no practical difference between "unknown" casualties and "no" casualties in a summary report of this type.

3. Sensitivity of Results to Toxic Fume Criteria (U)

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(~~S~~ U) ....

(U) In establishing threshold levels associated with the incapacitation criteria, the Surgeon General's Office considered two variables: time before the crew member masks, and time for the incapacitation to take effect. Masking time is an important variable because certain fumes are completely filtered by the masks.

(U) Table 37 gives an idea of the sensitivity of casualty results to the two variables. The table summarizes the results of Phase II offline tests in addition to the Phase II full-up tests. (These represent only those firings for which measurements showed some incapacitation of crew members. The data are useful for comparative purposes, but should not be considered representative of toxic levels for a typical combat shot.) Using the toxic fume levels measured during each shot, the levels of incapacitation were estimated according to various casualty criteria. The masking time was taken to be either immediate, 30 seconds one minute or five minutes. ("Immediate" masking means the crew member is either already wearing the mask or does not breathe until the mask is put on.) The time to incapacitaiton was either taken to be immediate or delayed (four hours or greater).

Table 37. (U) Sensitivity of Casualty Results to Toxic Fume Assessment Criteria

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(U) Table 37 indicates a noticable sensitivity of results to both time to mask and time to incapacitation for the fumes measured. Immediate masking will eliminate all toxic fume effects except for those from NO_X. Immediate masking is the appropriate criterion if troops are wearing masks when hit, or if they are able to hold their breath until masks are in place. The Army decided that a scenario of 30 second masking was more appropriate as a casualty criterion. The reasoning for a 30 second criterion was that within that time period the crew will either don their masks or leave the vehicle. Evacuation within 15 seconds was aplied to catastrohpic events where it was assumed the crew would attempt to leave the vehicle.

(U) With respect to the time to incapacitation criteria, the Army decided that the immediate incapacitation level was more consistent with the five minute assault casualty criteria used for determination of spall, overpressure and thermal effects, than would be the criteria of long term incapacitation (four hours or greater). Time to incapacitation was considered not a factor for HCN.

(~~S~~ U) ....

Table 38. (U) Sensitivity of Phase II Casualty Assessments to Toxic Fume Incapacitation Criteria: 30 Second Masking vs. no Masking, and Immediate vs. Delayed Effects

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(~~S~~ U) ....

(~~S~~ U) ....

III. COMPARISON OF REPORTS (U)

(U) A comparison was made of statements and conclusions on comparable issues as treated in the Army report on the Phase II Live Fire Test and in this report. For this comparison, it was assumed that the main points of each report were developed in their respective executive summaries. These were the primary sources for this comparison. Addressed here are matters related to execution of the test plan, presentation and analyses of the test data results and conclusions.

A. EXECUTION OF TEST PLAN (U)

(U) The foreword of the Army report notes that "Phase II testing was conducted in strict compliance with the Phase II Detailed Test Plans (DTP) for the BFVS Survivability Test dated 24 September 1986 (Phase IIA) and 20 February 1987 (Phase IIB)," with any requests for deviations approved by HQDA and OSD. This report fully concurs with this statement, based on observations of representatives of the Live Fire Test office of OSD who attended each firing. The execution of the test plan was managed exceptionally well, not only with respect to adherence to test plan guidance but in how much was accomplished within the scheduling constraints. The reporting was objective and data retrieval was generally high for tests of this nature. (For example, for the Halon interactions subtest, with eight total shots and instrumentation to record concentrations for five types of fumes (i.e., 40 cases), the Surgeon General's office lists lost data only for one fume type on one shot, a data retrieval rate of about 98 percent.)

B. PRESENTATION OF RESULTS (U)

(U) The Army report and this report have presented results in their respective summaries in response to either basic issues (Army report) or primary test objectives (this report). These differed because the objectives set forth in the Bradley Phase II Detailed Test Plans were stated only generally to "demonstrate the effectiveness of the survivability enhancements incorporated into the M2(HS) and M3(HS) vehicles and M2(ASTB) and M3(ASTB) vehicles" and "to generate baseline casualty, damage and vehicle vulnerability data." Although the listed Army "issues" and OSD "primary objectives" resulted in different organizational schemes for the presentation of results,

both reports address many of the same concerns when considered in toto. In addition to test results, the report summaries separately address the implications of the Bradley Live Fire Test with respect to the conduct of future live fire tests.

(U) The Army identifies the following five basic issues addressed by the Phase II full-up tests (Ref. 1):

> Issue No. 1 - Do the proposed High Survivability enhancements substantially increase the survivability of the crew (first priority) and/or the vehicle relative to the Basic Bradleys?
>
> Issue No. 2 - Do the proposed ASTB enhancements substantially increase the survivability of the crew (first priority) and/or vehicle relative to the HS vehicles?
>
> Issue No. 3 - What are the relative casualties for comparable impacts on M2 and M3 versions of each vehicle configuration?
>
> Issue No. 4 - What are the levels of overpressure, temperature, acceleration, and toxic fumes produced by impacts on each vehicle configuration?
>
> Issue No. 5 - What is the likelihood of a sustained fuel fire for 30mm KE, three-round bursts into the upper fuel cell of a Basic Bradley?

(U) By contrast, this report identifies specific objectives inferred from the shot selection rationale of the Detailed Test Plans. These were separately addressed as sections in the body of this report. Most of the findings are presented in the Summary in the form of two tables. One table presents the relative vulnerabilities of the Bradley test configurations: the Basic (B), High Survivability (HS) and the Advanced Survivability Test Bed (ASTB). The other table provides an evaluation of the various vulnerability reduction features found on the HS and ASTB configurations. The Summary also contains a separate section on crew casualties.

(U) In addition to the full-up test results, each report addresses the results of six off-line subtests conducted to aid in the interpretation of the full-up tests by isolating damage effects in a controlled environment. These were subtests of 25mm ammunition compartmentation, 25mm ammunition reaction, Halon interactions, behind armor debris (BAD), ready box vulnerability and live versus inert fuzed 25mm HEI-T ammunition.

C. RELATIVE VULNERABILITIES OF BRADLEY TEST CONFIGURATIONS (U)

(U) Statements in both reports germane to the relative vulnerabilities of the three Bradley test configurations (Basic, HS and ASTB) are presented in Table 39. It would appear that the two reports are in essential agreement in all respects, except for comparison of the HS and Basic Bradley vulnerabilities to the 30mm KE projectiles. The Army report describes the results as mixed; this report states that the HS and ASTB vehicles provided better protection than that provided by the Basic Bradley.

Table 39. (U) Comparison of Army and OSD Reports: Relative Vulnerabilities of the Bradley Test Configurations (Basic, HS and ASTB)

(~~SECRET~~ UNCLASSIFIED)

D. SPECIFIC ISSUES AS IDENTIFIED IN ARMY REPORT (U)

(U) There follows below comparisons of the Army report and this report regarding the five specific issues used to structure the Army report.

(U) Army Issue No. 1 - Do the proposed High Survivability enhancements substantially increase the survivability of the crew (first priority) and/or the vehicle relative to the Basic Bradley?

Army Report	This Report
(~~S~~ U)	(~~S~~ U) ....
• **RPG-7G Threat (U)**	• **RPG-7G Threat (U)**
(~~S~~ U)	(~~S~~ U) ....
	(~~S~~ U) ....

Army Report

- **30mm KE Threat (U)**

(~~S~~ U) ....

This Report

- **30mm KE Threat (U)**

(~~S~~ U) ....

Army Report	This Report
• **Large Caliber Threats (TOW/TOW 2 and 120mm) (U)**	• **Large Caliber Threats (TOW/TOW 2 and 120mm) (U)**
(~~S~~ U)	(~~S~~ U) ....
	(~~S~~ U) ....
	(~~S~~ U) ....

Army Report	This Report
• **Problems Identified (p. vi) (U)**	• **Problems Identified (U)**
(~~S~~ U)	(~~S~~ U) ....

(U) Army Issue No. 2 - Do the proposed ASTB enhancements substantially increase the survivability of the crew (first priority) and/or vehicle relative to the HS vehicles?[3]

<u>Army Report</u>	<u>This Report</u>
(~~S~~ U)	(~~S~~ U) ....
(~~S~~ U)	

<u>Army Report</u>	<u>This Report</u>
• **RPG-7G Threat (U)**	• **RPG-7G Threat (U)**
(~~S~~ U)	(~~S~~ U) ....
• **30mm and Large Caliber Threats (U)**	• **30mm and Large Caliber Threats (U)**
(~~S~~ U)	(~~S~~ U) ....

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[3] (U) This type of comparison of the ASTB and HS vehicles could also be phrased differently "Do the proposed BFVS(HS) enhancements substantially increase the survivability of the crew (first priority) and/or vehicle relative to the BFVS(ASTB) vehicles?" The answer, based on the results would be "yes" for the RPG-7G threat and "no" for the other threats (Army report p. vii; this report p.9).

(U) Alternately, the question may be asked "Are there survivability enhancement features which are unique to either the HS or ASTB vehicles and which substantially increase Bradley survivability?" The answer is "yes," examples being the reactive armor on the HS vehicle and the ammunition compartments with "blowout" panels and external fuel cells on the ASTB. (Army report pp. vi, vii; this report p. 9)

(U) Army Issue No. 3 - What are the relative casualties for comparable impacts on M2 and M3 versions of each vehicle configuration?

Army Report	This Report
(~~C~~ U)	(~~C~~ U) ....

(U) Army Issue No. 4 - What are the levels of overpressure, temperature, acceleration, and toxic fumes produced by impacts on each vehicle configuration?

Army Report	This Report
(U) "Main penetrator impacts on the propellant or explosive sections of on-board ammunition pose the greatest hazard to the personnel in all three vehicle configurations." (p. vii)	(~~C~~ U) ....
(~~C~~ U)	
• **Blast Overpressure (U)**	• **Blast Overpressure (U)**
(~~S~~ U)	(~~S~~ U) ....

Army Report

- **Thermal (U)**

(U) The small number of burns assessed were mostly associated with reaction of ammunition propellant. Fuel fires that were quickly suppressed were not a significant burn hazard. "Thermal injuries can be minimized by wearing uniform sleeves rolled down and using gloves and facial protection when available." (p. viii)

This Report

- **Thermal (U)**

(~~C~~ U) ....

Army Report

- **Toxic Gases (U)**

(U) Much of this description is abstracted from the assessment by the Office of the Surgeon General.

(U) "A significant risk of injury from the inhalation of toxic gases may exist inside a perforated BFV which is otherwise combat effective. Oxides of nitrogen (NO_x) from ammunition fires pose the greatest hazard to the crew. Pyrolysis products of Halon 1301 from both fuel and ammunition products were occasionally found to be significant hazards, most often in association with high levels of NO_x. The vast majority of the hazard occurs prior to masking. The risk of delayed injury can be decreased by having soldiers minimize physical exertion for 24 hours after exposure."

(U) Comment: This last suggestion may be considered unrealistic by some, considering that the situation is one where the pesonnel are in a vehicle that has just been hit and is in the direct fire zone.

This Report

- **Toxic Gases (U)**

(~~C~~ U) ....

(~~C~~ U) ....

Army Report	This Report
• **Acceleration (U)**	• **Acceleration (U)**
(~~C~~ U)	(~~C~~ U) ....
• **Flash (U)**	• **Flash (U)**
(~~C~~ U)	(~~C~~ U) ....

(U) Army Issue No. 5 - What is the likelihood of a sustained fuel fire for 30mm KE, three-round bursts into the upper fuel cell of a Basic Bradley?

Army Report	This Report
(~~C~~ U)	(~~C~~ U) ....

E. OFF-LINE SUBTESTS (U)

1. 25mm Ammunition Compartmentation (U)

Army Report	This Report
(~~C~~ U)	(~~C~~ U) ....
	(~~C~~ U) ....

2. 25mm Ammunition Reaction (U)

Army Report

(~~S~~ U) ....

(U) Note: It was also an objective of the tests to provide instrumentation data to the Office of the Surgeon General to evaluate the Bradley environment. This was done. See comments above for Issue No. 4.

(~~S~~ U) ....

This Report

(~~S~~ U) ....

3. Halon Interactions (U)

Army Report

(U) See comment above on Toxic Gases. Also, "benefits of the ability of the Automatic Fire Suppression System to extinguish fuel fires in the crew occupied areas outweigh the health risk from neat Halon 1301 and pyrolysis products." (p. ix)

This Report

(~~C~~ U) ....

4. Behind Armor Debris (BAD) (U)

Army Report

(~~S~~ U) ....

This Report

(~~S~~ U) ....

5. Ready Box Vulnerability (U)

Army Report	This Report
(~~C~~ U)	(~~S~~ U) ....

6. Live Versus Inert Fuzed 25mm HEI-T (U)

Army Report	This Report
(~~C~~ U)	(U) "The results of off-line tests addressing this issue were similarly inconclusive, because of both the limited number of firings devoted to this issue as well as firings that did not impact their intended locations due to dispersion induced by dynamic firing of the RPG-7G munitions." (p. 36) (U) "Although the full-up test and off-line tests alone were considered inconclusive, additional tests (Ref. 11) showed virtually no difference in the likelihood of sympathetic detonation to adjoining rounds whether the 25mm HEI-T test rounds were live fuzed or inert fuzed. Further, the design of the fuze was considered to preclude the possibility of a difference in effects. Therefore, additional tests were not considered necessary in this case." (p. 36)

(U) Comment: The language used by assessors in describing results of impacts into ammunition usually had terms such as "reacted violently." This was done both for ammunition with non-explosive APDS projectiles and for ammunition with potentially explosive HEI-T warheads, so that it is apparent the language was used for propellant reactions. Only rarely were distinctions used for "warheads detonated" and propellant "exploded," yet such distinctions are important for diagnostics, since the warhead detonations should be more brisant and cause more potent fragments than propellant reactions. It would be helpful in the future if more precise language than "ammunition reacted violently" were used.

(U) The supplementary tests (Ref. 11) showed that sympathetic warhead detonations take place whether the fuzes on the warheads are live or inert. An additional question is whether initiation of any of the explosive elements of an unarmed fuze (as when struck by a jet from the RPG-7G or TOW) will cause a

warhead detonation. In view of the relatively small presented area of the fuze compared with the warhead and the fact that the warhead will generally detonate when hit by a jet, even if detonation of some part of the unarmed fuze did initiate the warhead, the difference in overall vulnerability would be small.

F. FUTURE THREATS (U)

Army Report	This Report
(U) "TOW/TOW 2 are representative of current and future Soviet anti-tank guided missiles." (p.iv)	(U) "The threat weapons...were considered representative of a spectrum of current overmatching threats that the Bradley might be expected to encounter in combat." (p. 9)

(~~C~~ U) ....

G. IMPLICATIONS OF BRADLEY LIVE FIRE TEST FOR CONDUCT OF FUTURE LIVE FIRE TESTS (U)

(U) The summaries of both the Army report and this report address some implications for future live fire tests based on the experience with the Bradley Live Fire Test Program (this report's Summary Section B; Army report p. ix). In general, the two summary sections spoke to different issues, although the report bodies were more similar in the issues addressed.

(U) This report (with parenthetical references to the Army report) observes that:

- Instrumentation developed for the Bradley live fire program represents a vast improvement over past vulnerability tests but there is a need to improve and validate the methodologies for evaluation of overpressure and toxic fume data. (This point was also made by the Office of the Surgeon General in the body of the Army report.)

- The emphasis on crew casualties is appropriate. (This is not stated explicitly in the Army report, although the body of that report gives considerable attention to factors affecting crew casualties.)
- There exist some needs which must be addressed.
  - Evidence is needed of likely crew response to slowly developing fires and the trauma of being hit.
  - The SDAL should be documented, to include an estimate of the variability of the input subjective judgments.
  - The computer model predictions, in the form provided to OSD, were of limited utility.
  - Improvement of the computer model's predictive capability is needed. (This report summary suggests a number of ways to to this.)
- The random (BAST methodology) and prescribed ("engineering assessment") shots each played a unique and necessary role in live fire testing.
- Off-line tests, by isolating damage effects in a controlled environment, can be useful in interpreting full-up results that otherwise may have been inconclusive.
- Future live fire tests will continue to have to address the comparative effects of targets with live fuzed versus inert fuzed ammunition.

(U) The statement in the Army summary on implications from the Bradley live fire tests is quoted below.

> (U) Finally, we believe live fire testing is necessary and beneficial. A balanced mix of component and ballistic hull and turret testing, full-up vehicle firings, and modeling is the most cost effective approach. Over-reliance on very expensive full-up vehicle firings and random shotline selections driven by considerations other than "smart testing" can lead to the generation of minimal information at great cost. Program managers of combat vehicle systems and all others involved in developing items/materiel which eventually will be part of or stowed in combat vehicles must put vulnerability reduction as a priority throughout the development process. We must take advantage of these lessons if live fire testing is to remain beneficial and affordable.

(U) It is not clear whether the Bradley live fire tests were considered by the Army to suffer from "over-reliance on very expensive full-up vehicle firings and random shotline selections driven by considerations other than 'smart testing.'"

H. EFFECTIVENESS OF THE ENHANCEMENT FEATURES (U)

(U) The findings of the two reports were in substantial agreement with respect to the effects of the various vulnerability reduction features. However, this report presents,

in addition to evidence of effectiveness of the various enhancement features, some potential drawbacks to be considered in any tradeoff analyses as well as comments or evaluation relevant to the tradeoff analyses. (See Table 9.)

I. CREW CASUALTIES (U)

(U) The Summary of this report separately addresses the issue of crew casualties, a priority concern for the Bradley. The Army report treats the matter of crew casualties extensively in the report body and discusses crew casualties in its summary as part of the responses to each of the issues it identified.

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APPENDIX A

ESTIMATES OF BRADLEY VULNERABILITIES USING ANALYTIC MODELS (U)

APPENDIX A
ESTIMATES OF BRADLEY VULNERABILITIES USING ANALYTIC MODELS (U)

(U) Tables A-1 and A-2 summarize the output from Army vulnerability models which were updated based on the results of the Bradley Phase II Live Fire Test. Printouts from model runs were transmitted to the Live Fire Test Office in tabular form (Ref. 17), with numeric values assigned to each four-inch grid cell of the presented area of the Bradley, for four attack azimuths (0, 90, 180 and 270 degrees).

Table A-1. (U) Average Values of Pk (M, F, K) and Expected Casualties for a Uniform Distribution

(~~SECRET~~ UNCLASSIFIED)

Table A-2. (U) Average Values of Pk (M, F, K) and Expected Casualties vs. Azimuth

(~~SECRET~~ UNCLASSIFIED)

(U) Analytic estimates were obtained for four threat weapons: 30mm KE, RPG-16, 120mm KE and TOW 2. The 30mm KE, 120mm KE and TOW 2 were of the type used in the live fire test. The RPG-16 was not used in the live fire test, but is considered similar in lethality to the RPG-7G.